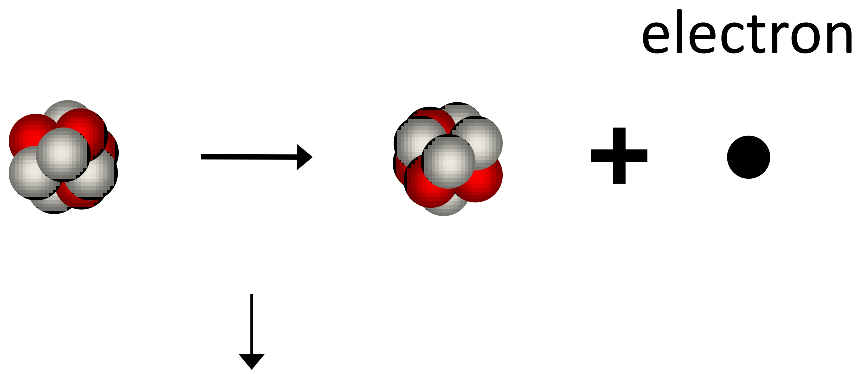
Neutrino Astro-Particle Physics

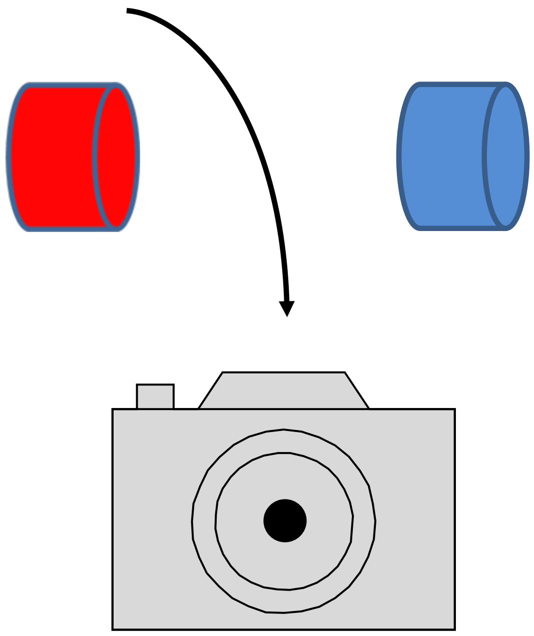
Maarten de Jong
Nikhef/Leiden

2011

What is a neutrino?

Radioactive decay (~1920)

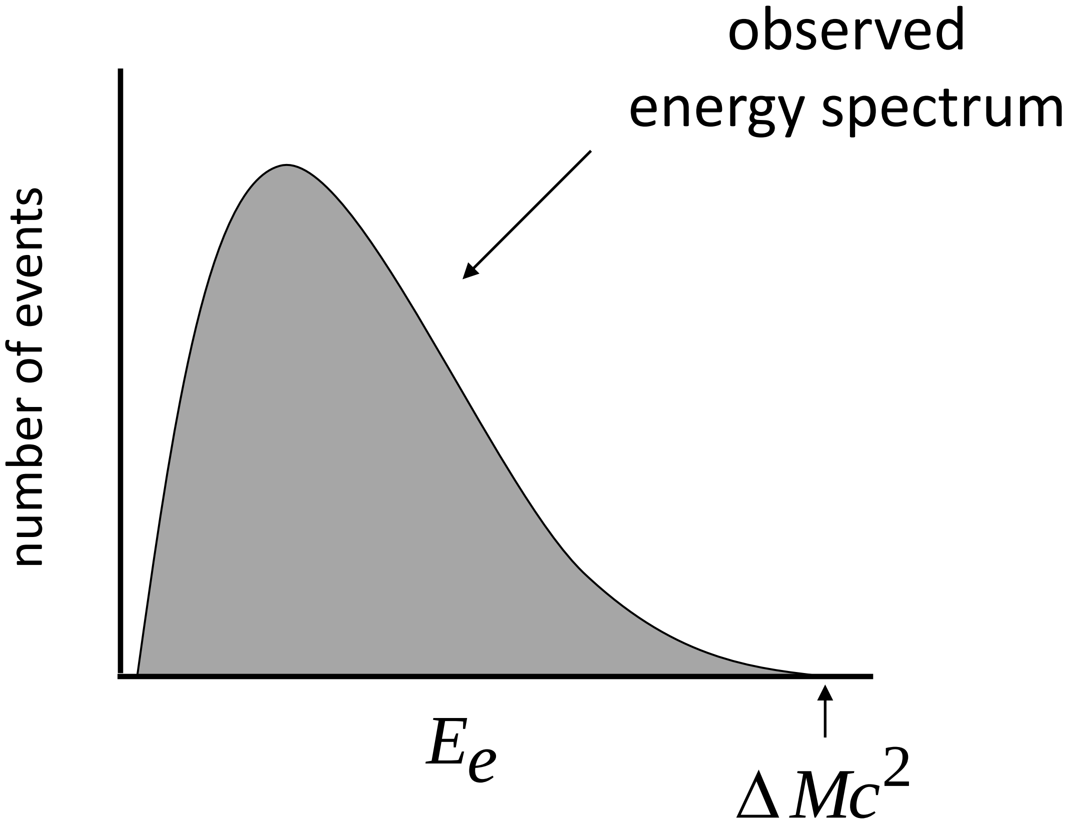




2-particle decay?

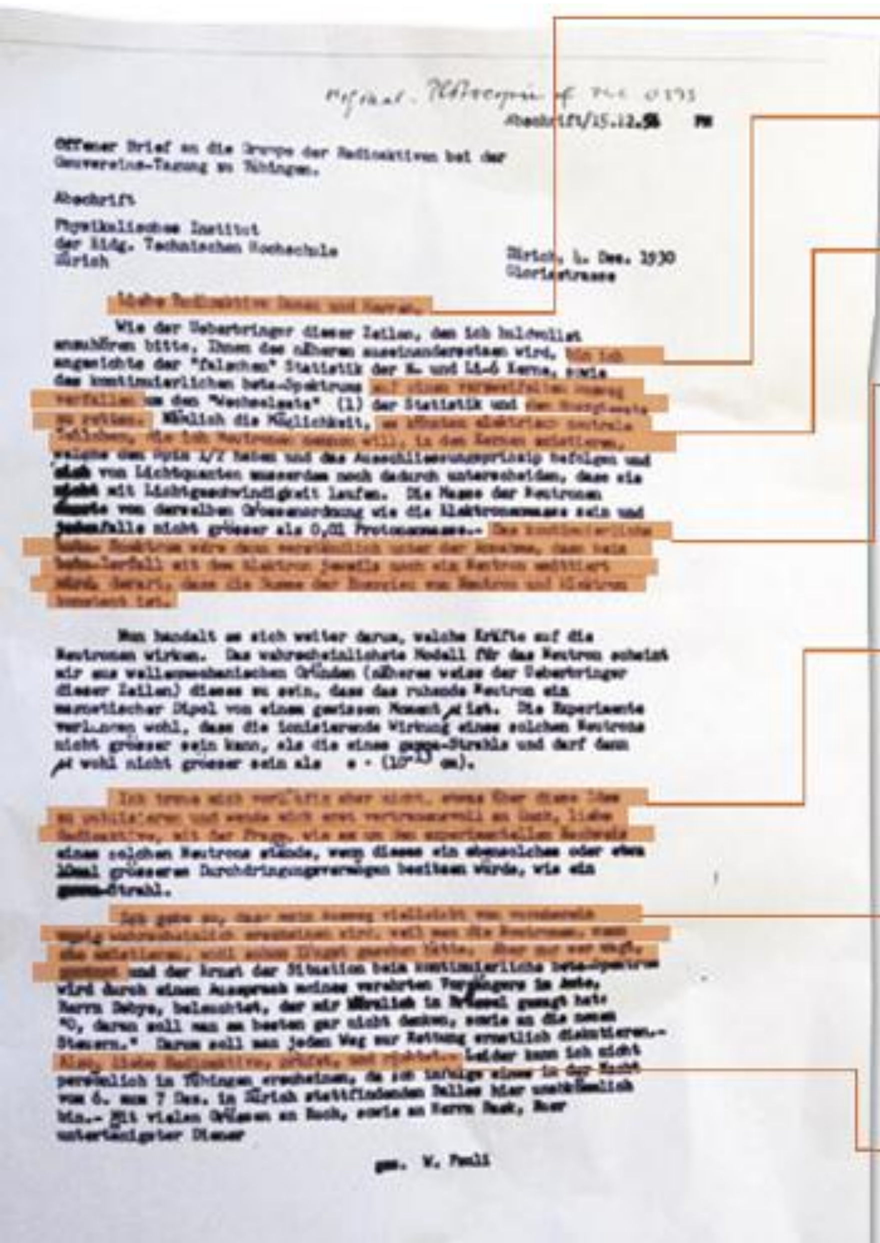
Einstein: $$E_e = \Delta M c^2$$

Radioactive decay (II)



Energy not conserved?

W. Pauli, 4 December 1930



Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

gez. W. Pauli

Dear radioactive ladies and gentlemen,

I may have found a solution to the energy crisis in radioactive decays.

… the existance of electrically neutral particles –which I call neutrons– in the atomic nucleus.

The measured spectrum can be understood if such a neutral particle escapes together with the electron such that the total energy is conserved.

But until now I did not dare to publish this idea and I ask you –radioactive people– whether it is possible to detect this particle experimentally.

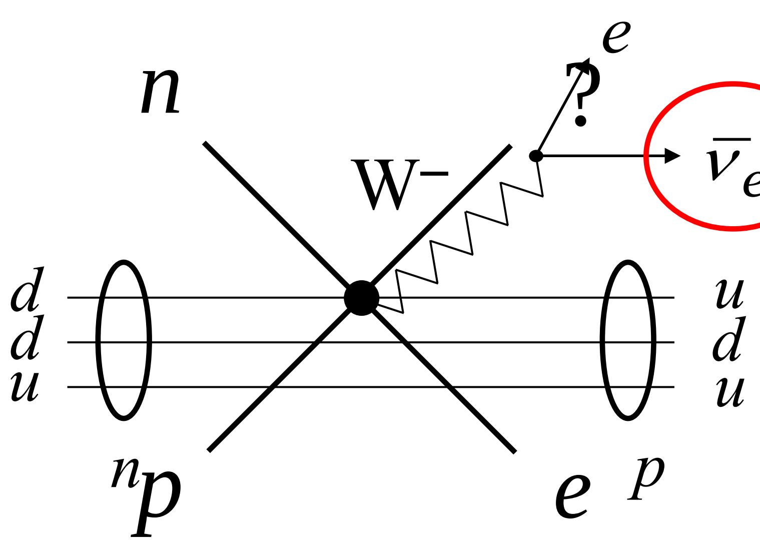
I admit that this idea is unlikely because the neutrons –if they exist– would have been found altready.

So, dear radioactive people, think about this idea and judge.

Pauli (1930): $n \rightarrow p + e + \bar{\nu}_e$

Fermi: Theory of weak interaction

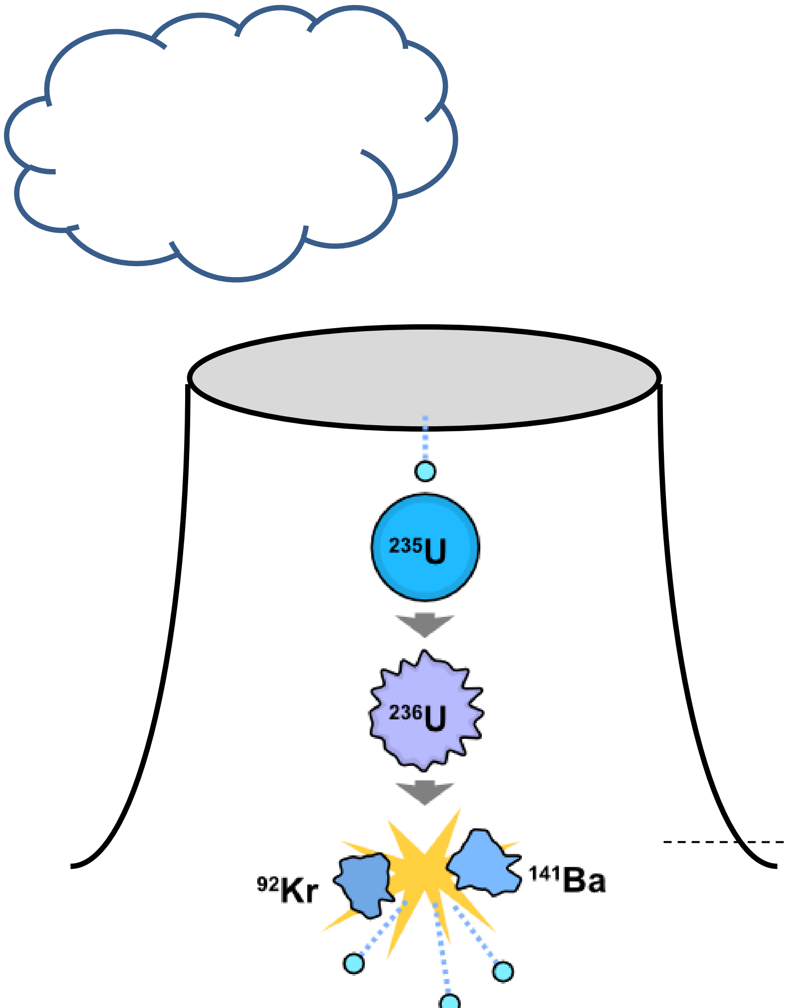
neutrino



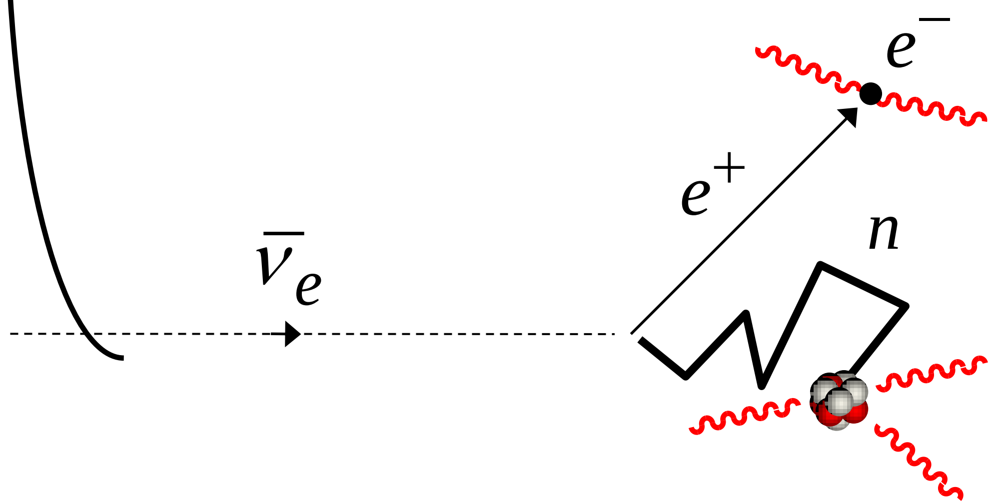
Feynman diagram

1950 – Reines & Cowan
“Poltergeist”, Savannah River

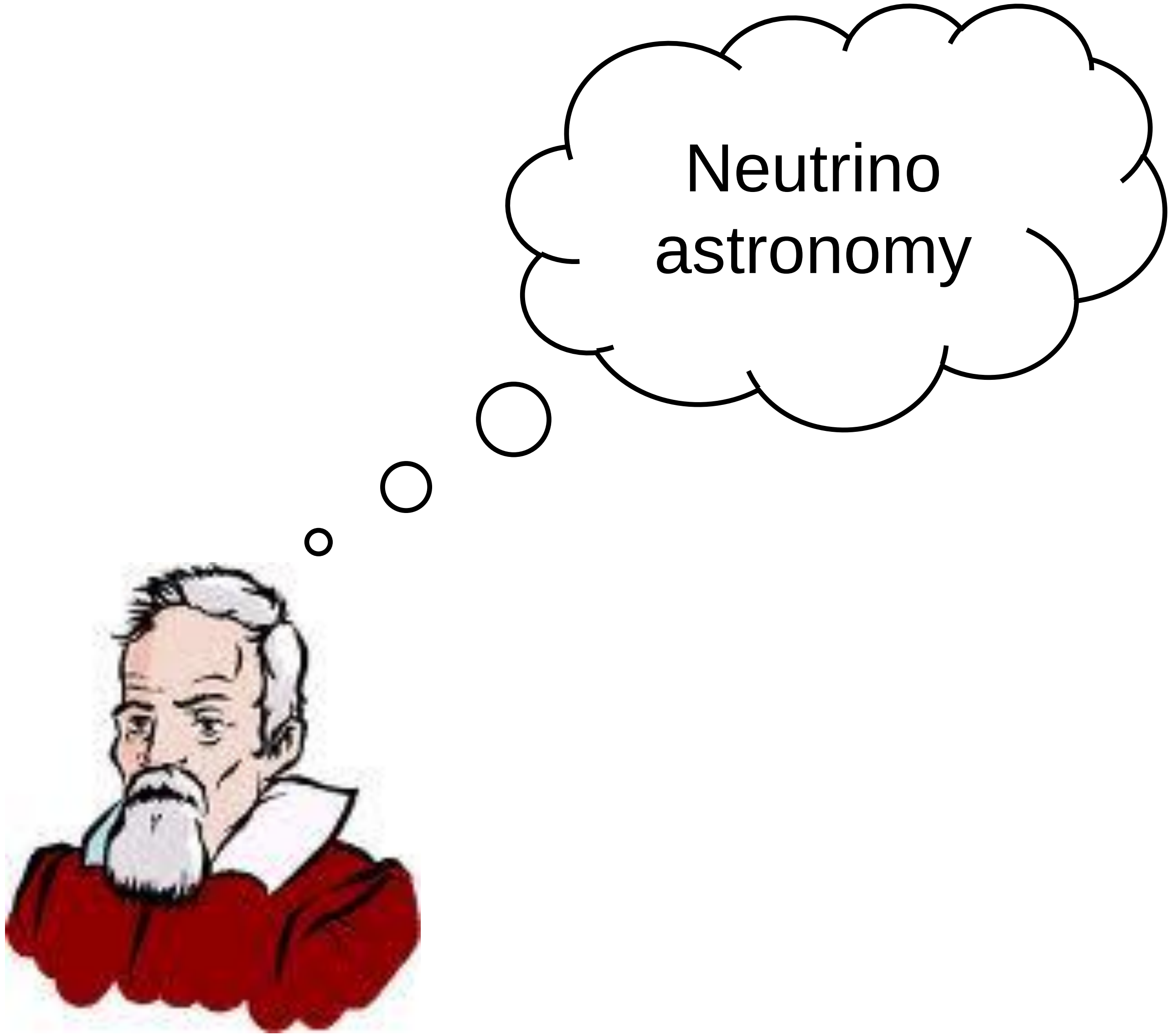
Experimental evidence existance of neutrinos



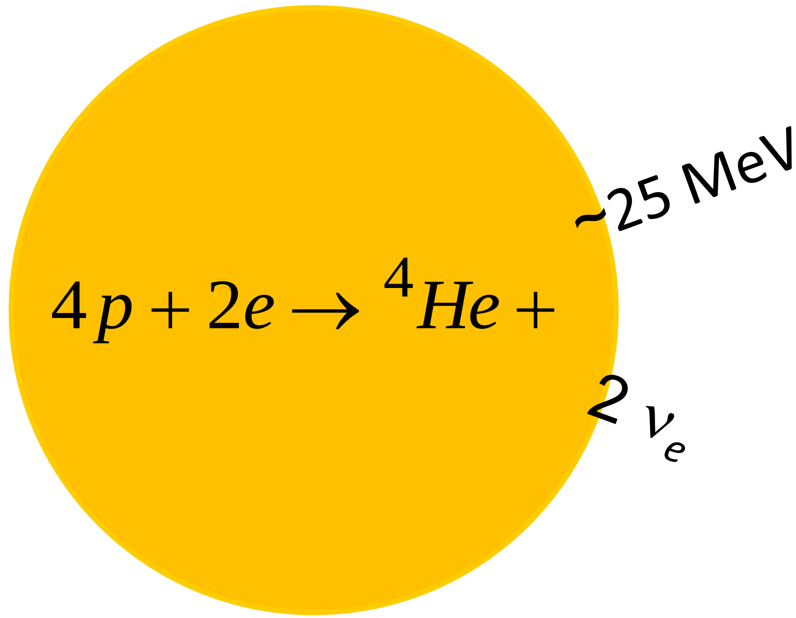
nuclear reactor



neutrino detection


Neutrino
astronomy

Sun



Light yield $L_{\odot} = 3.92 \times 10^{26}\ W$

neutrinos $N_{\nu_e} = 2 \dfrac{L_{\odot}}{1.6 \times 10^{-13} \times 25\ MeV} \approx 1.8 \times 10^{38}\ s^{-1}$

Homestake gold mine (USA)

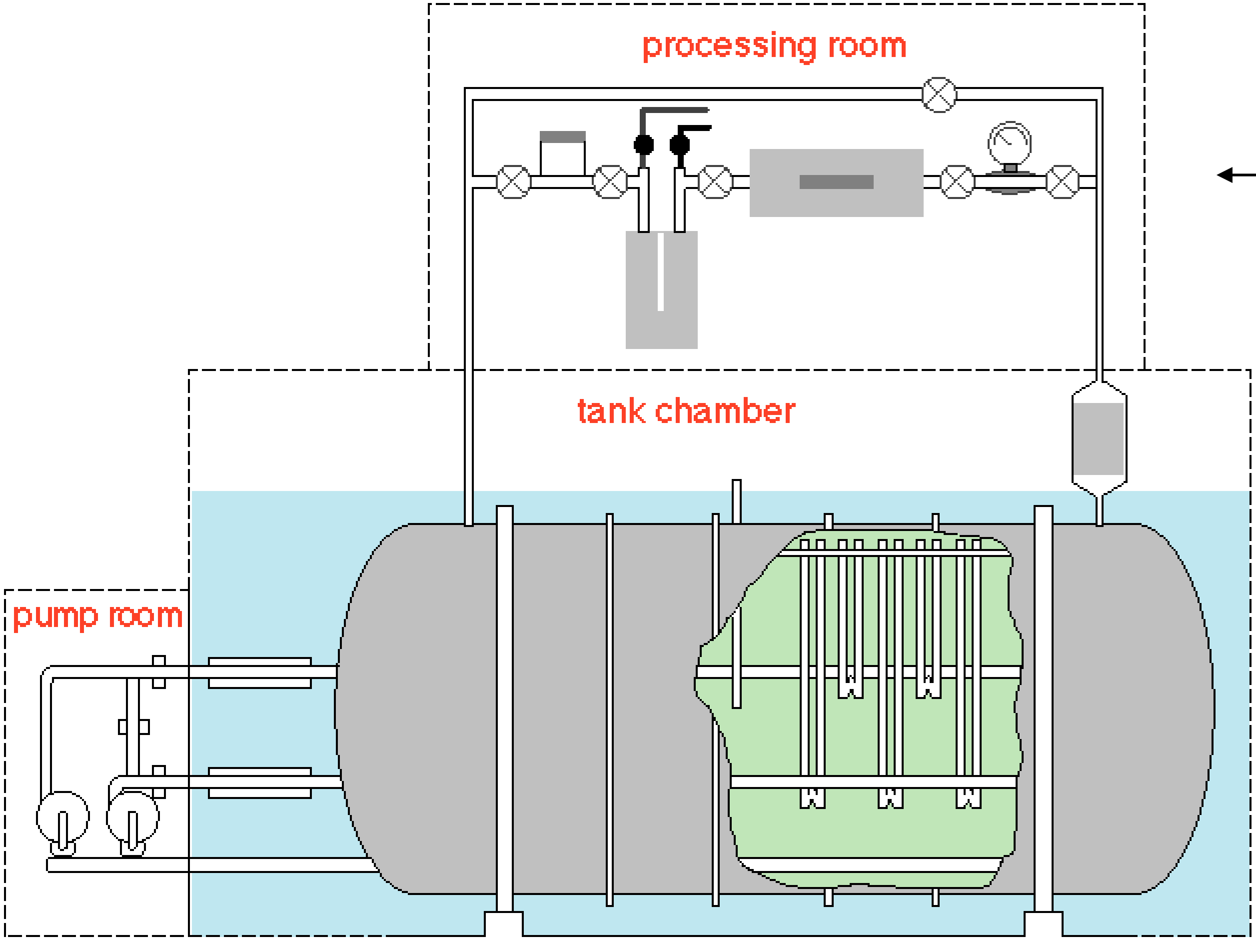
"inverse decay"

$$\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^-$$

130 ton Chlorine

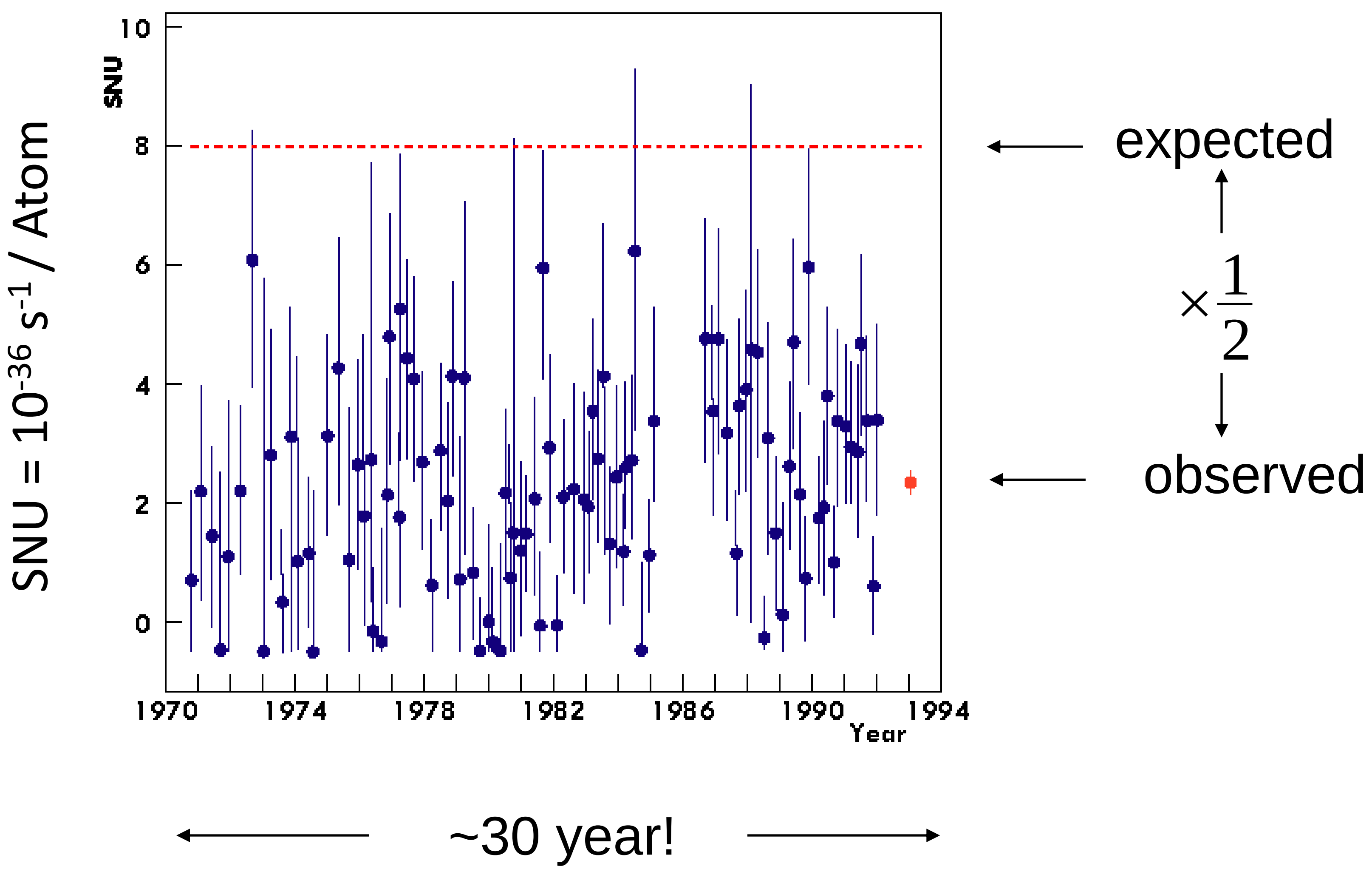
$$E_{\nu_e} \geq 0.814\, MeV$$

detection principle



extraction
few Ar atoms
(~15 / month)

Neutrinos from the sun

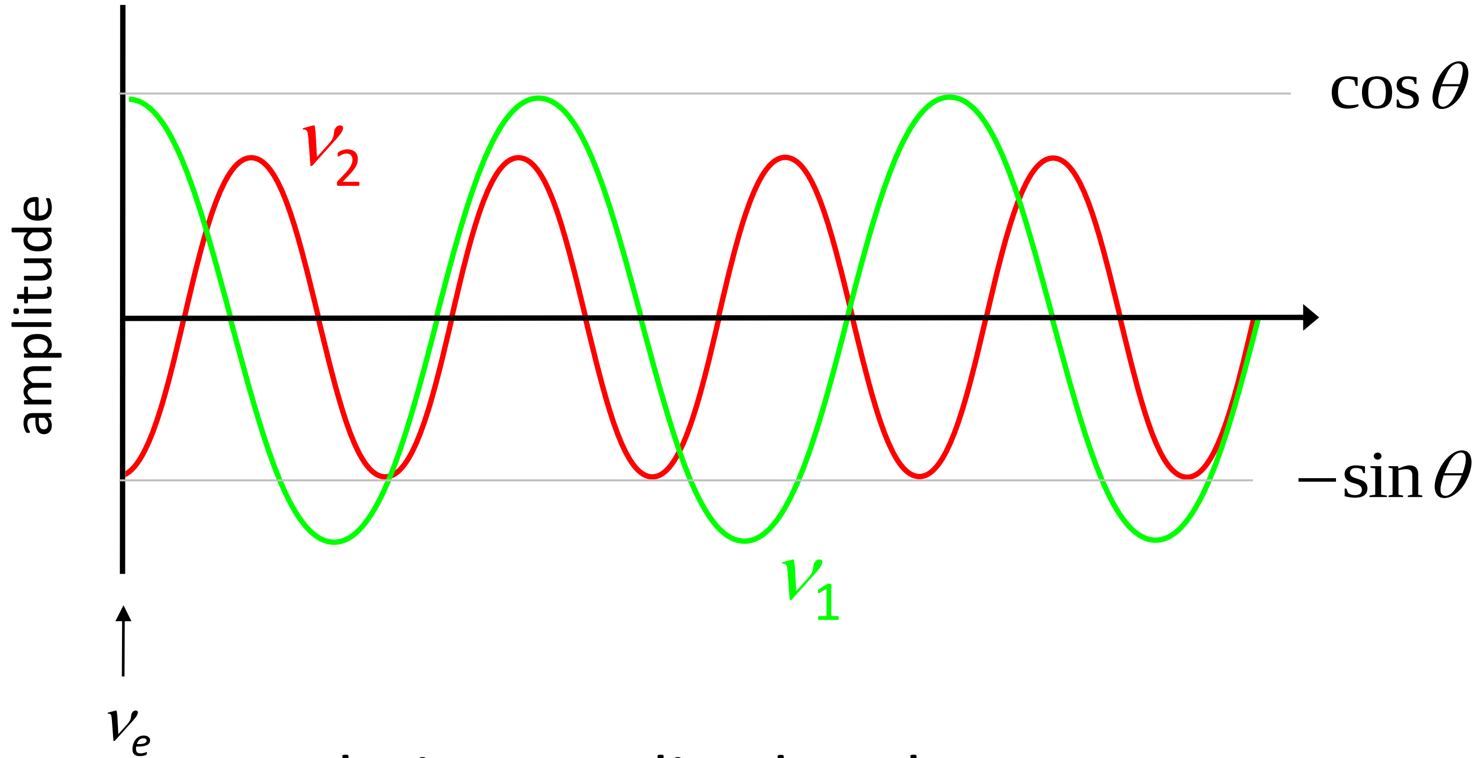


Observe ½ neutrinos from the sun

⇓

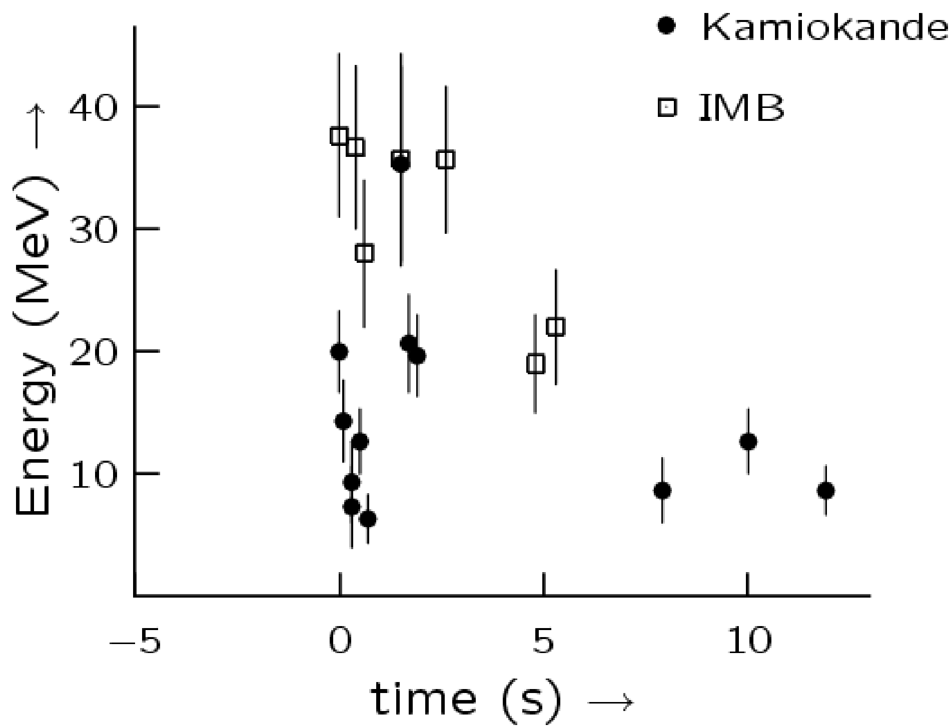
neutrino oscillations

Travelling of neutrinos through space



relative amplitudes change
as a function of time or distance

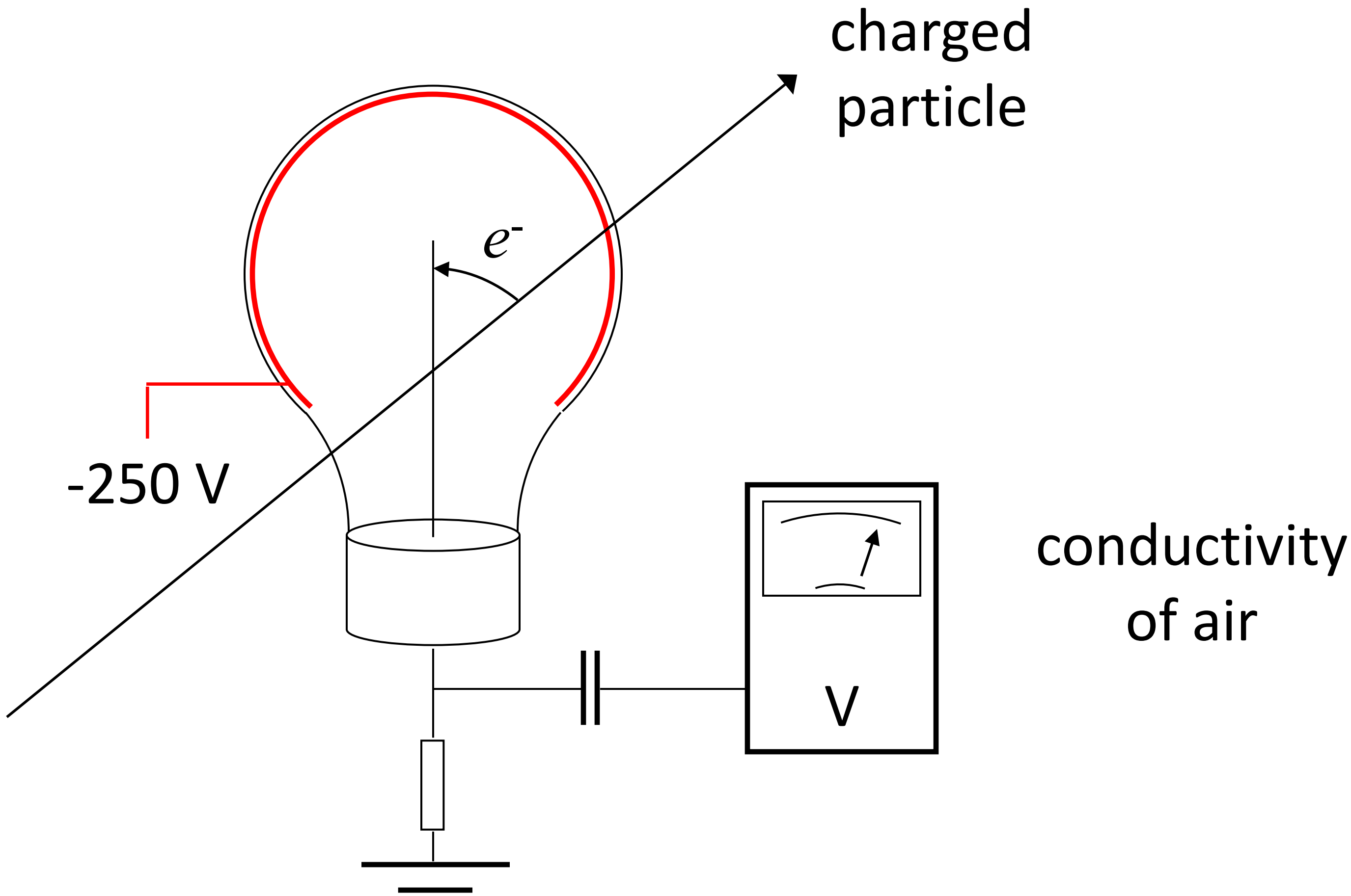
23 February 1987



Thermal neutrinos from Supernova (□ 99% of energy!)

Why high-energy neutrino astronomy?

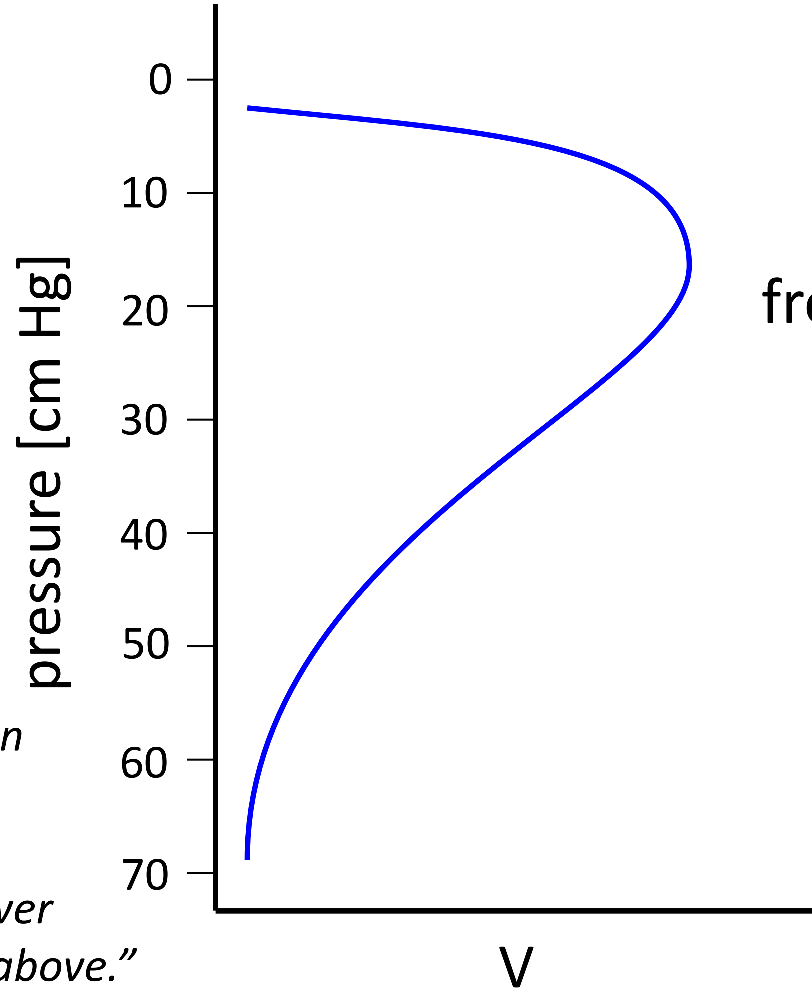
Ionisation chamber (~1910)



Earth' radioactivity?

V. Hess (1912)

"*The results of my observation are best explained by the assumption that a radiation of very great penetrating power enters our atmosphere from above.*"



radiation from outer space!

↓

cosmic rays

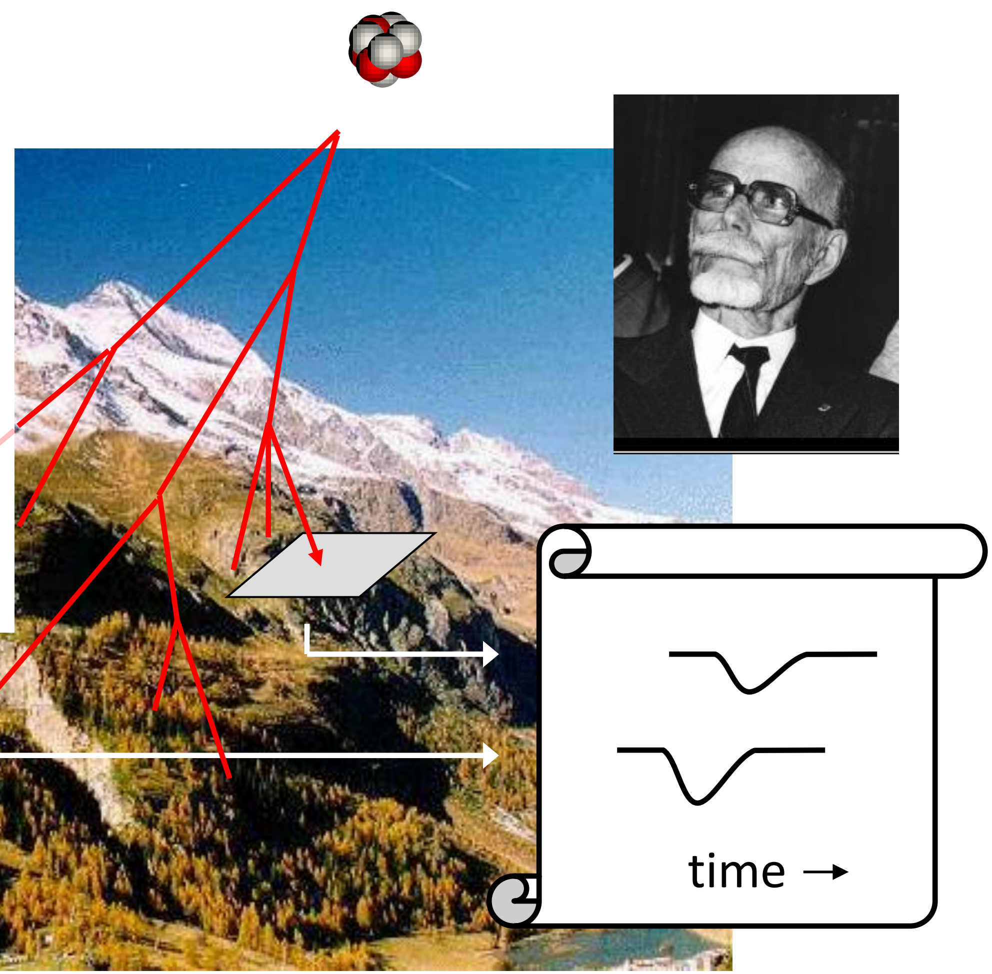
Earth

P. Auger (1938)

Extensive Cosmic-Ray Showers

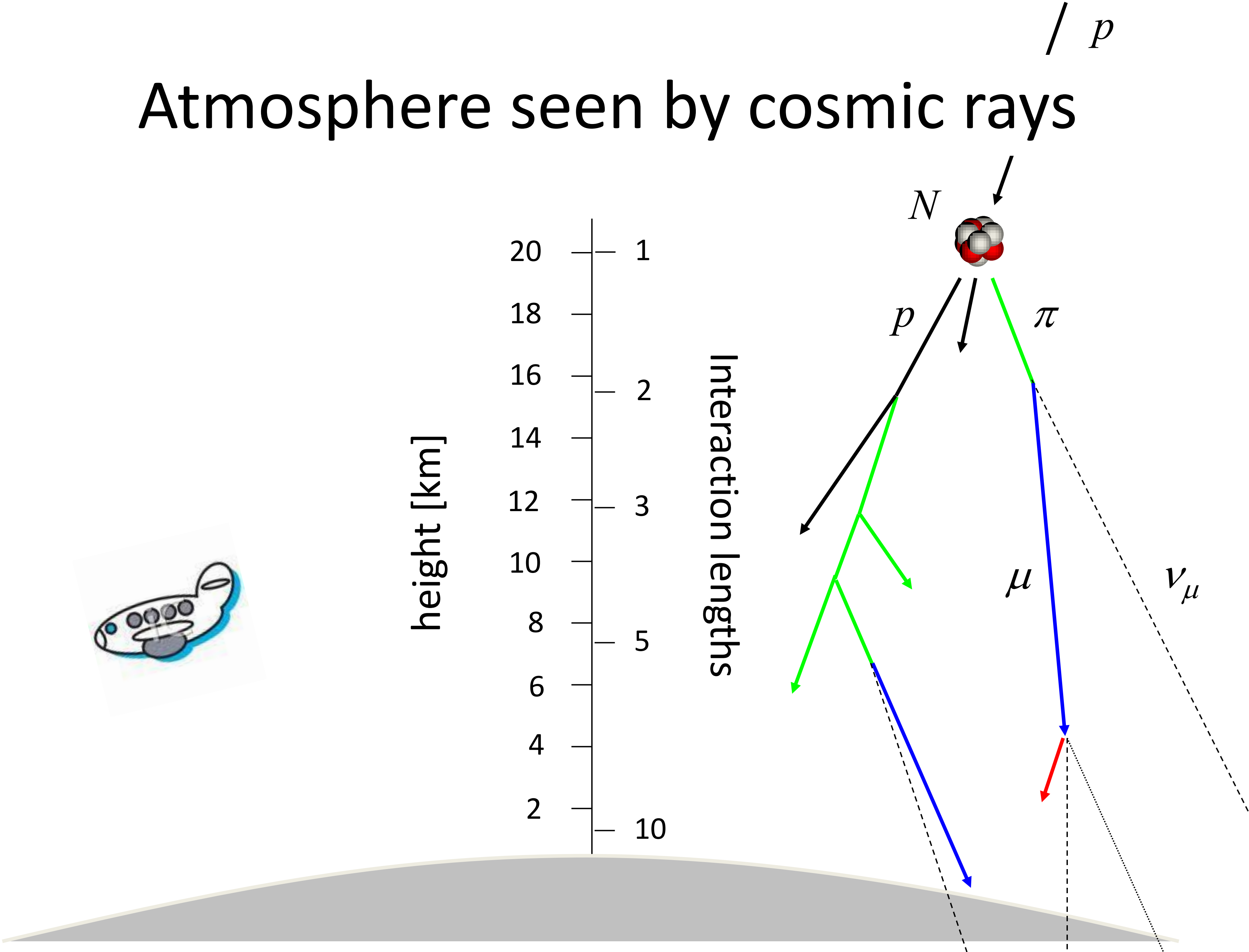
PIERRE AUGER
In collaboration with
P. EHRENFEST, R. MAZE, J. DAUDIN, ROBLEY, A. FRÉON
Paris, France

One of the consequences of the extension of the energy spectrum of cosmic rays up to 10^{15} ev is that it is actually impossible to imagine a single process able to give to a particle such an energy. It seems much more likely that the charged particles which constitute the primary cosmic radiation acquire their energy along electric fields of a very great extension.

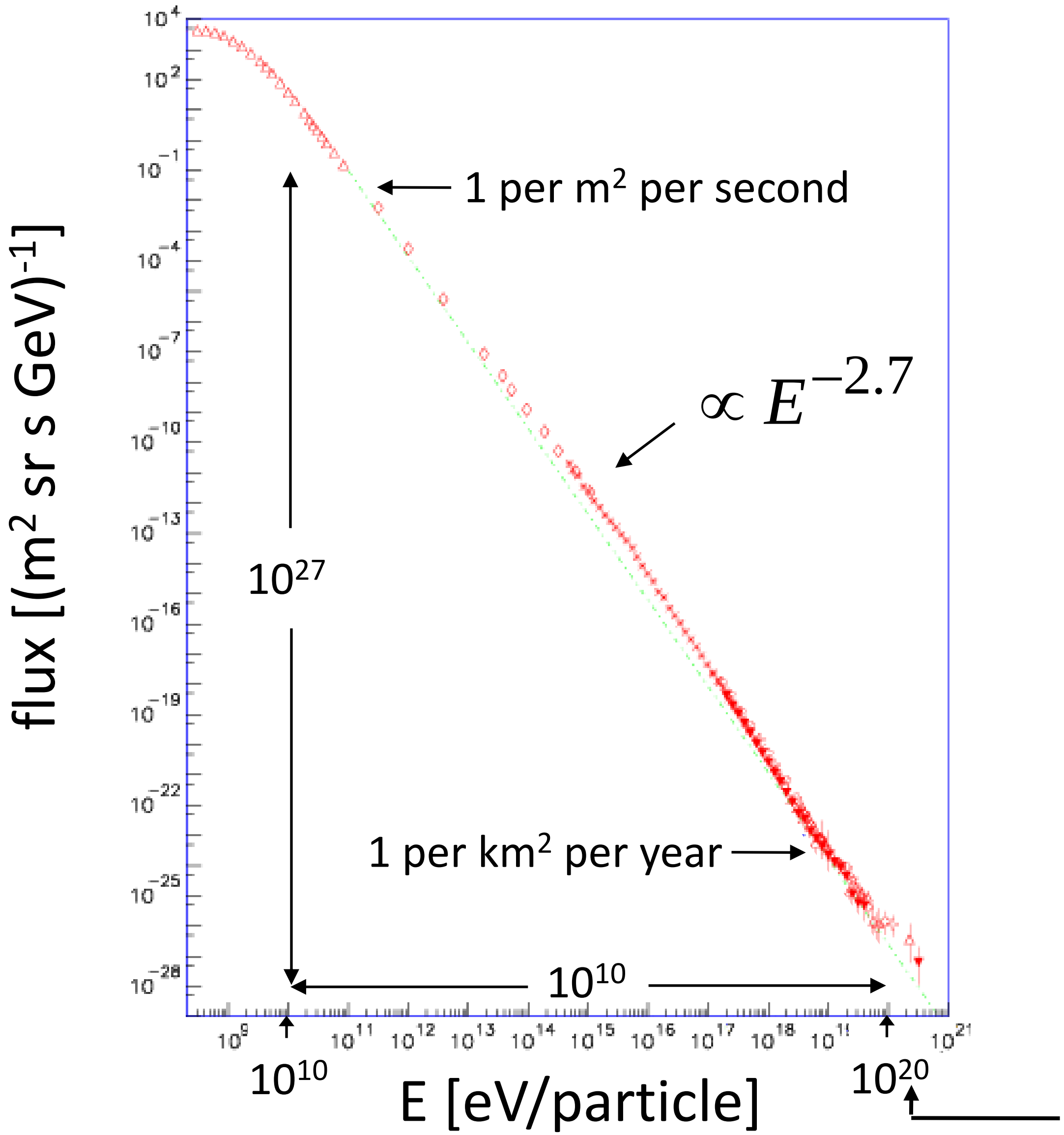


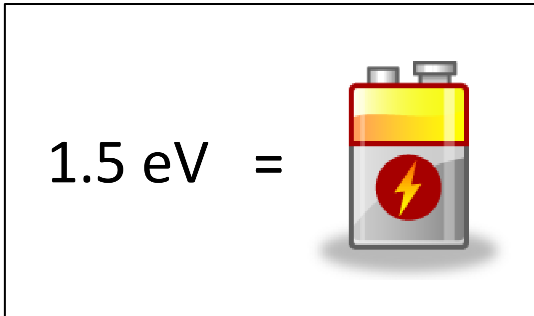
“Astrophysical particle acceleration”

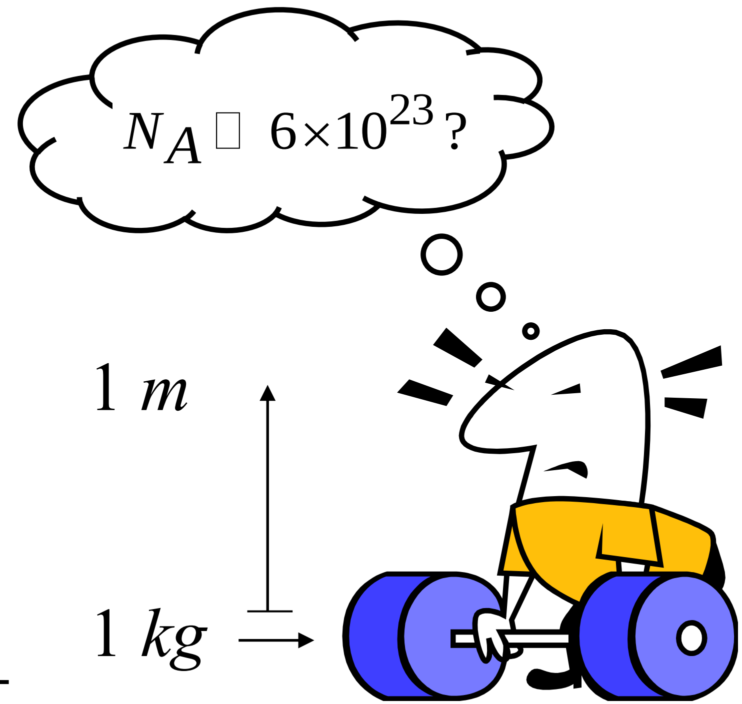
Atmosphere seen by cosmic rays



Energy spectrum

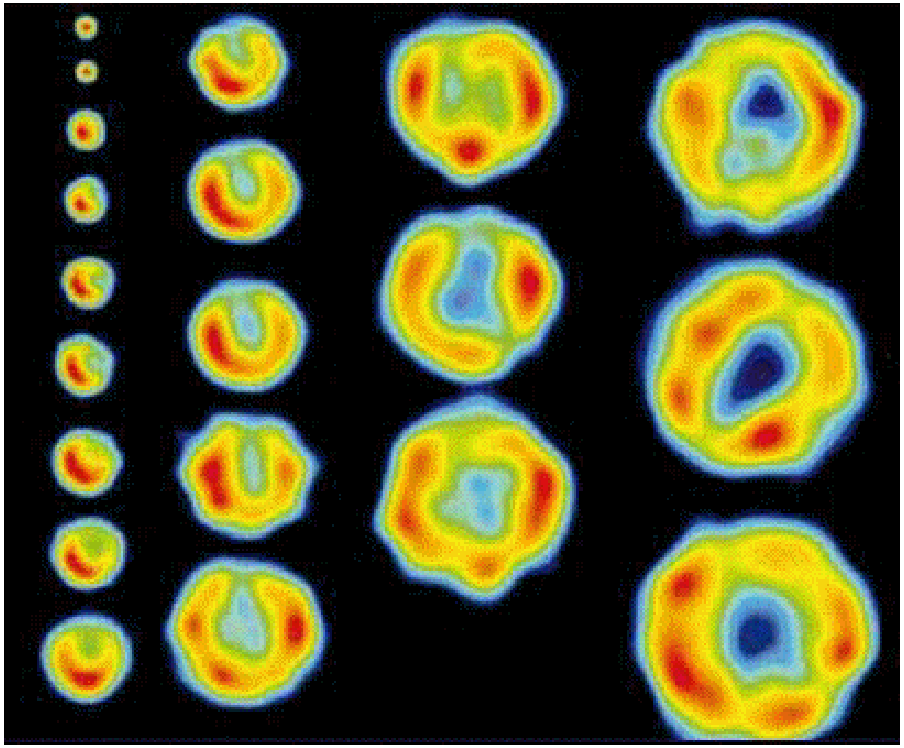






SN1993J – M81

initial
expansion speed
~ 20000 km/s

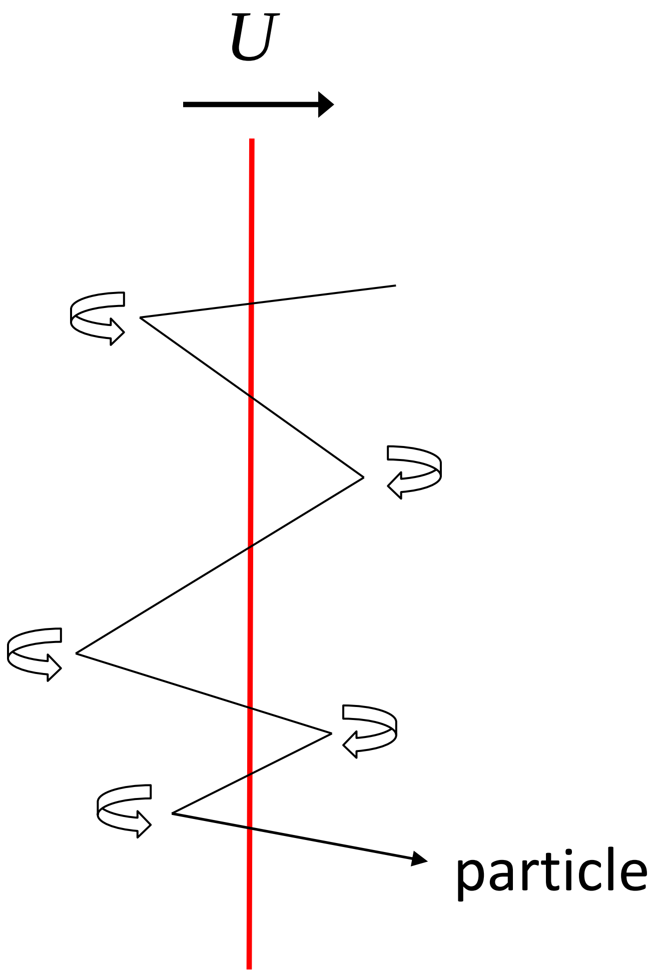


radio maps April 1993–June 1998

<u>What you see</u>:

The heating of cold interstellar gas by the expansion of a Super Nova shell

Fermi shock acceleration



Simple model

Acceleration	$\Delta E = \alpha E$
Probability	$P = \beta$

↓

k steps	$E = E_0 (1+\alpha)^k$
	$N = N_0 (\beta)^k$

Energy spectrum

$$\frac{\ln(N/N_0)}{\ln(E/E_0)} = \frac{\ln(\beta)}{\ln(1+\alpha)}$$

$$\frac{N}{N_0} = \left(\frac{E}{E_0}\right)^{\frac{\ln(\beta)}{\ln(1+\alpha)}}$$

Thermodynamics

$$\frac{dN}{dE} \propto E^{\frac{\ln(\beta)}{\ln(1+\alpha)}-1} = E^{-2}$$

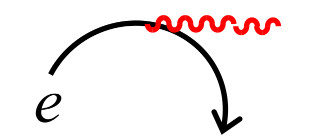
□ Observed spectrum

Relativity

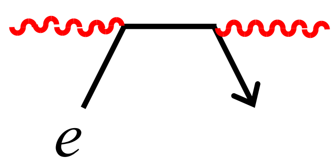
Which particles?

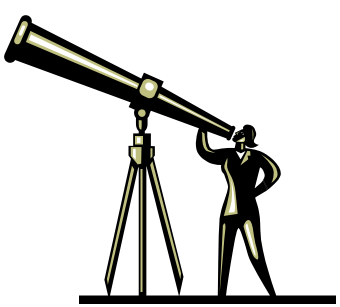
electrons

Synchroton radiation



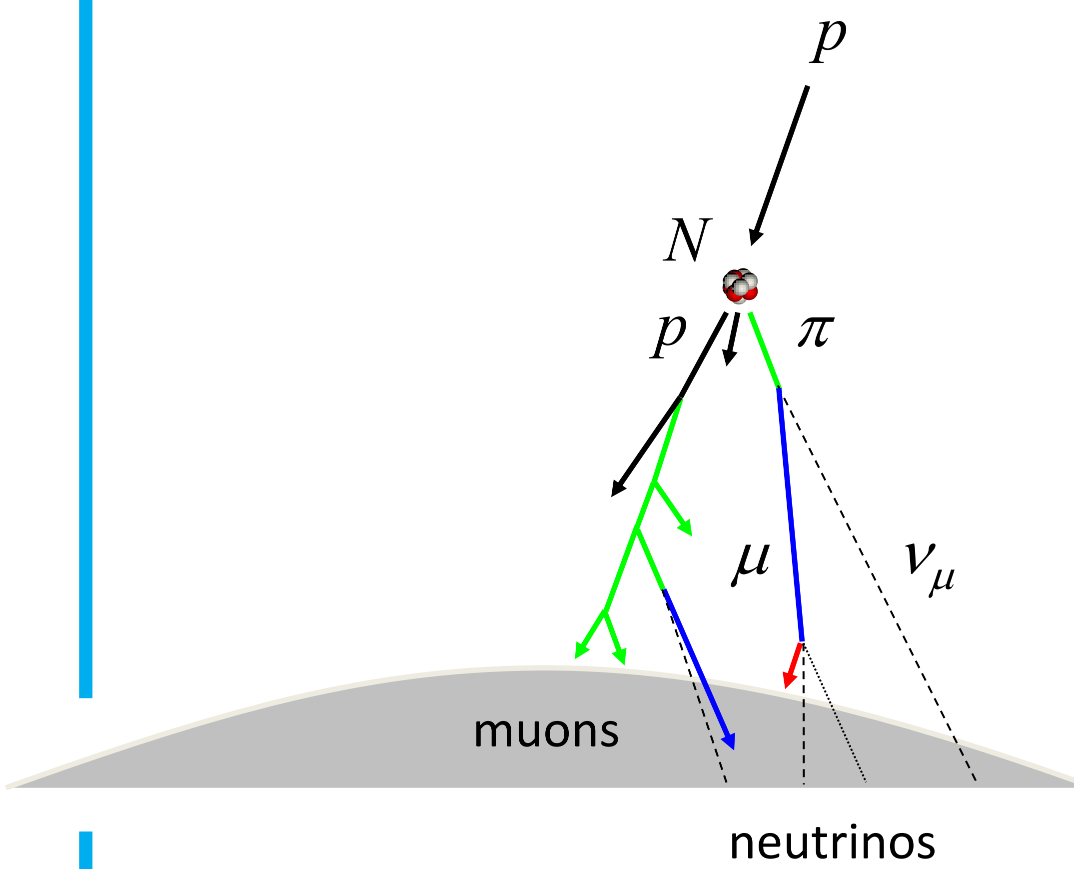
inverse Compton scattering





astronomy

protons



cosmic rays

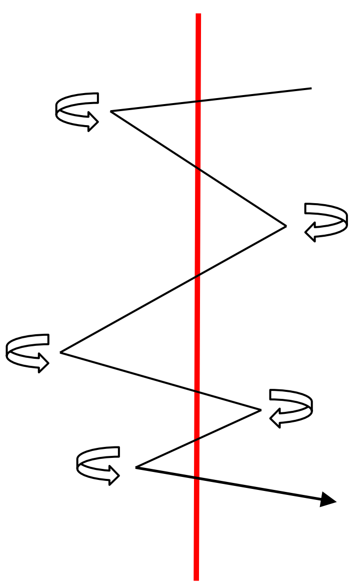
Multi-messenger astronomy

$e + \gamma \longrightarrow e + \gamma$ | Electro-Magnetic

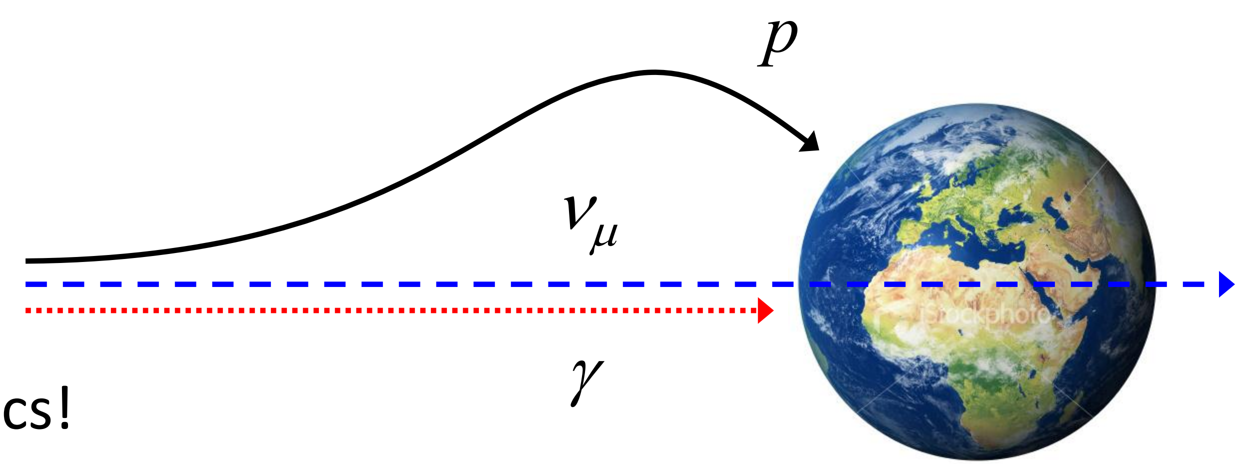
$p + p \longrightarrow \pi^+ \pi^- \pi^0$

$\pi^\pm \longrightarrow \mu^\pm + \nu_\mu$ | Hadronic

$\pi^0 \longrightarrow \gamma\gamma$

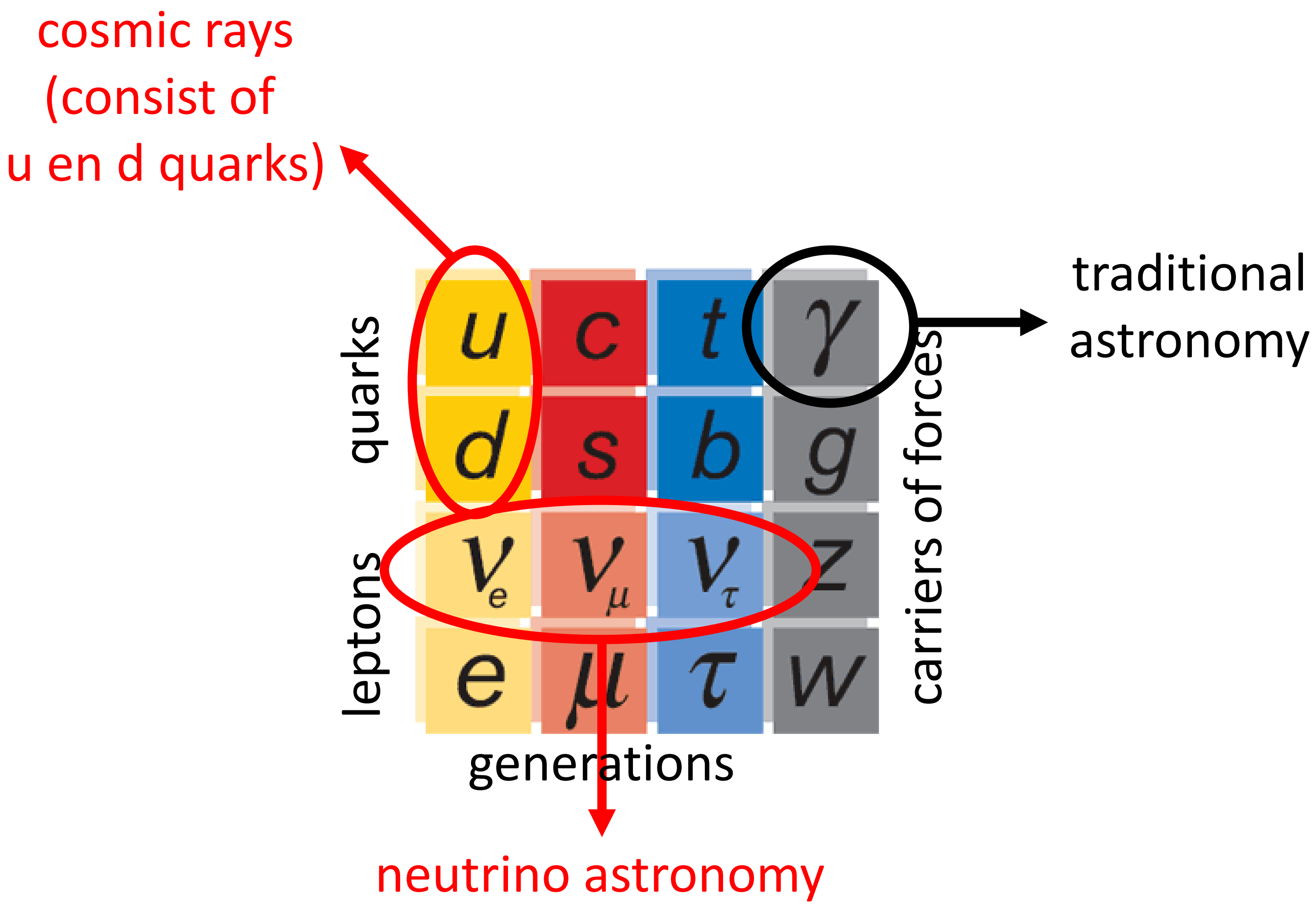


?



particle physics!

Astro-particle physics



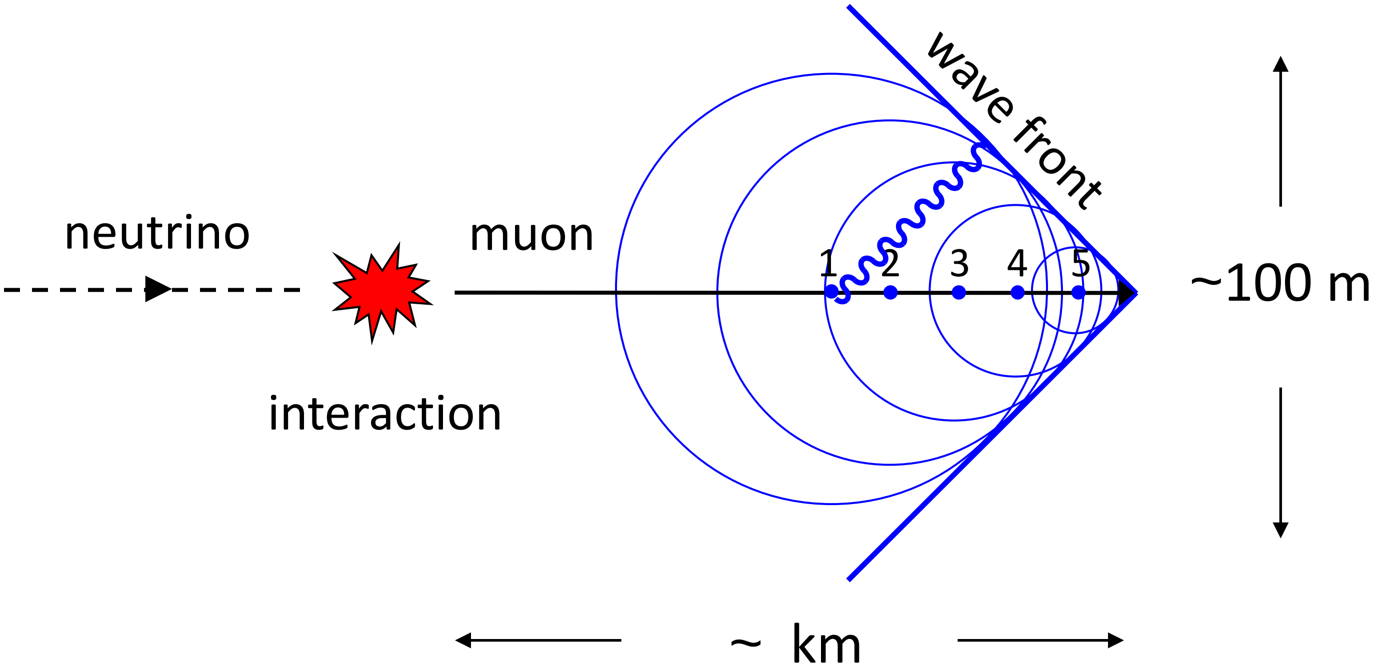
How?

1960 Markov's idea:

Seawater as interaction and detection medium

- Length muon trajectory
- Detection Cherenkov light
- Water is transparant

neutrino detection

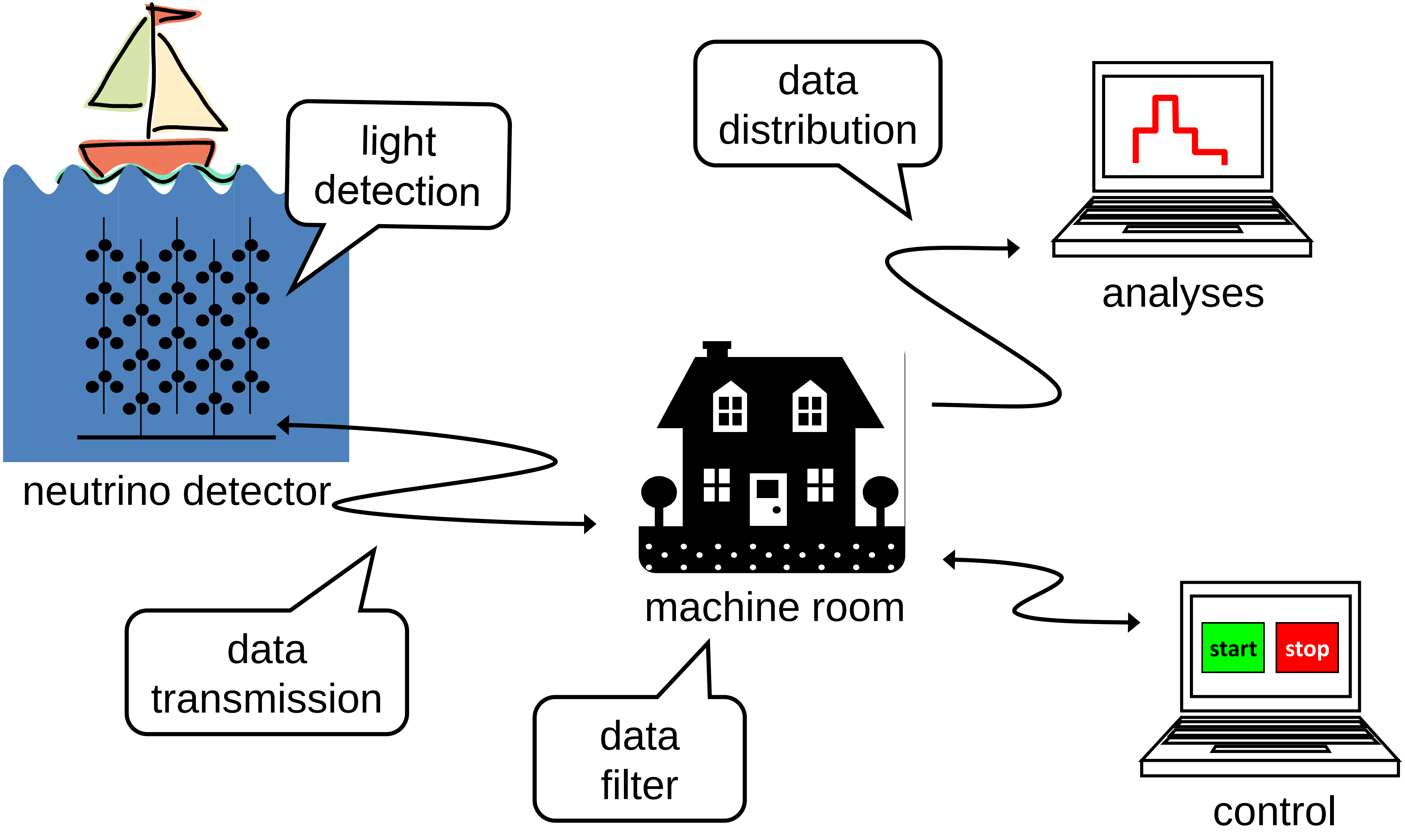


muon travels with the speed of light (300,000 km/s)

⇩

detection Cherenkov light *ns – km*

Architecture

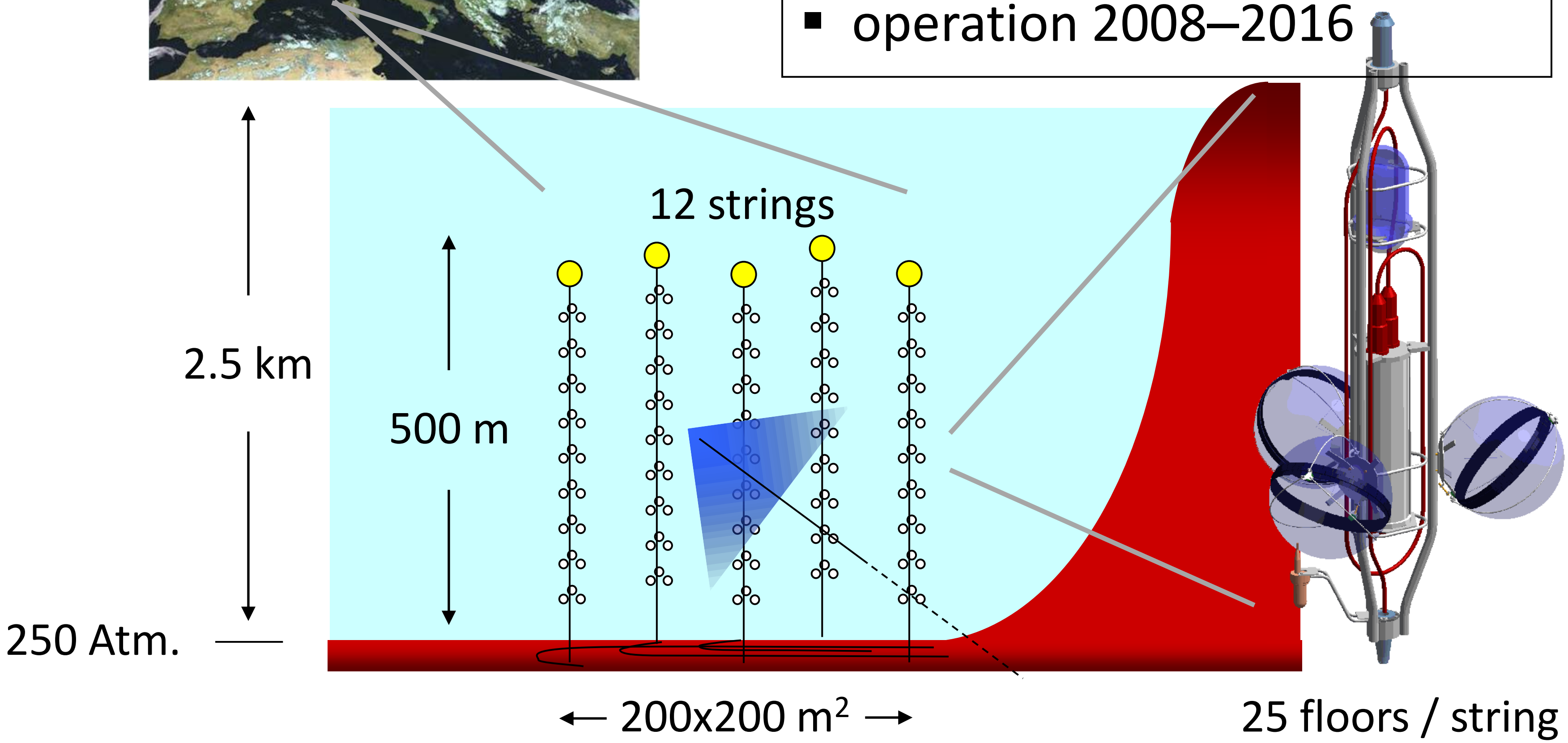


Antares

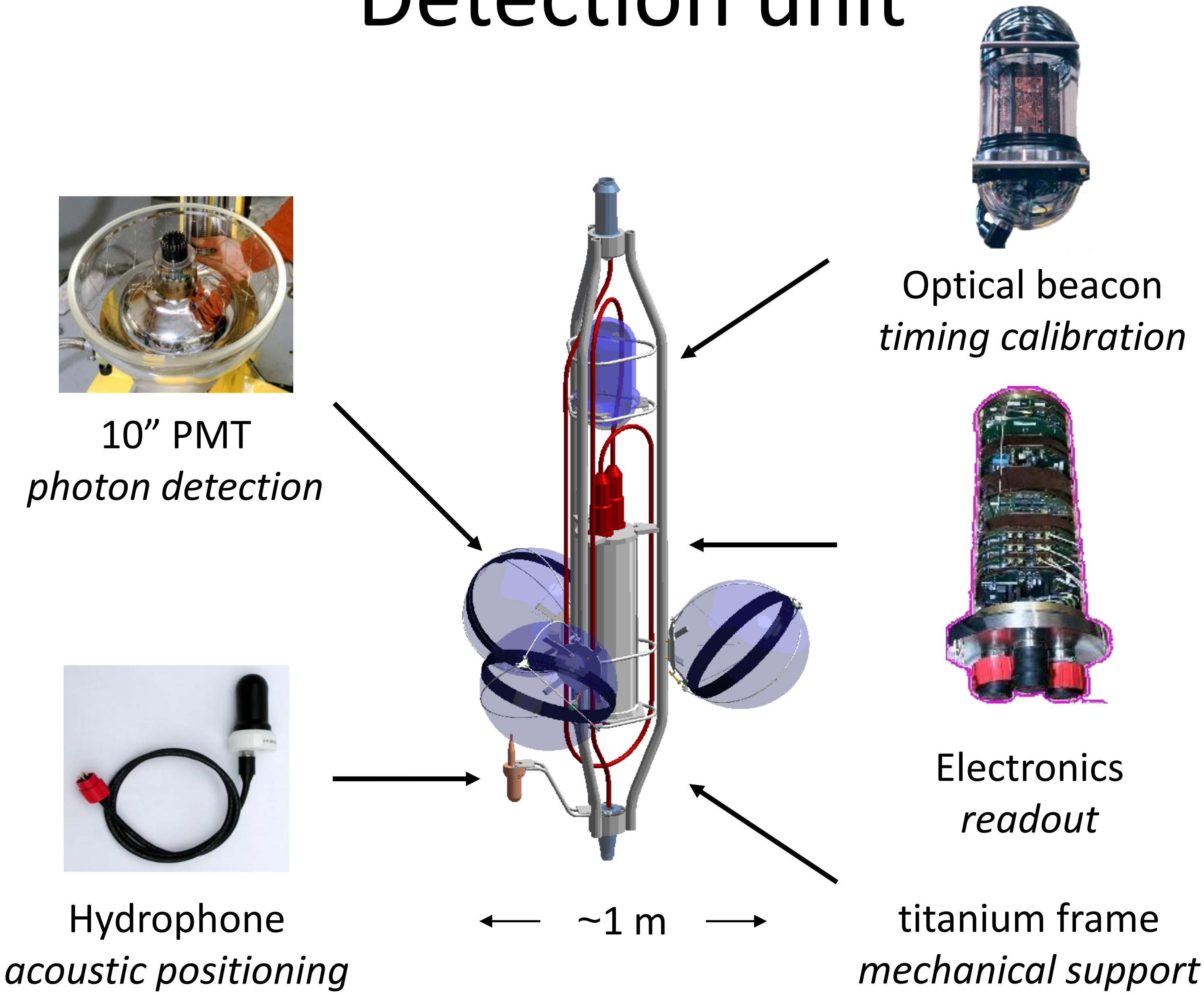
prototype neutrino telescope

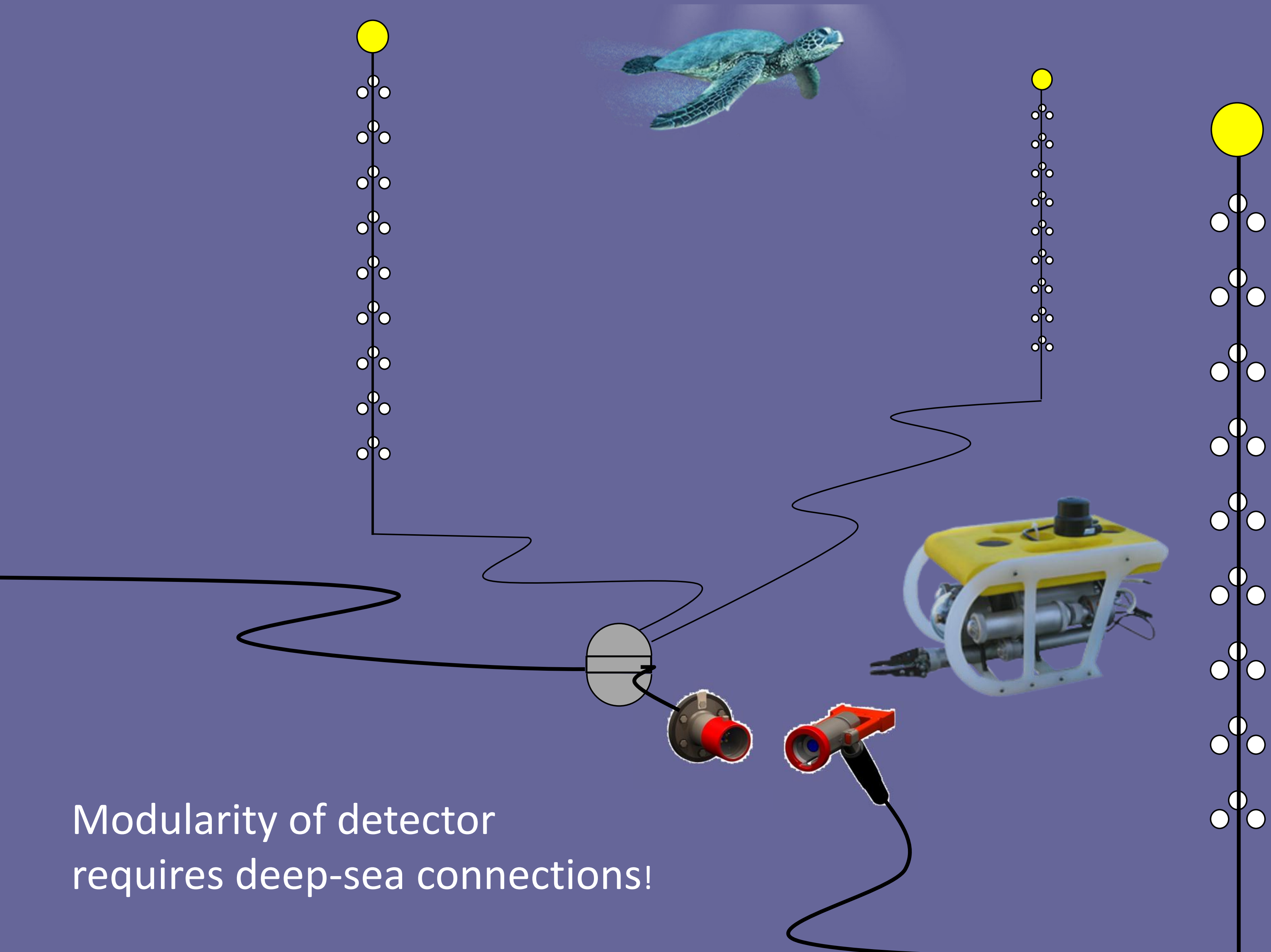
Antares

- 200 persons
- 6 countries
- 40 km off the coast of Toulon
- operation 2008–2016



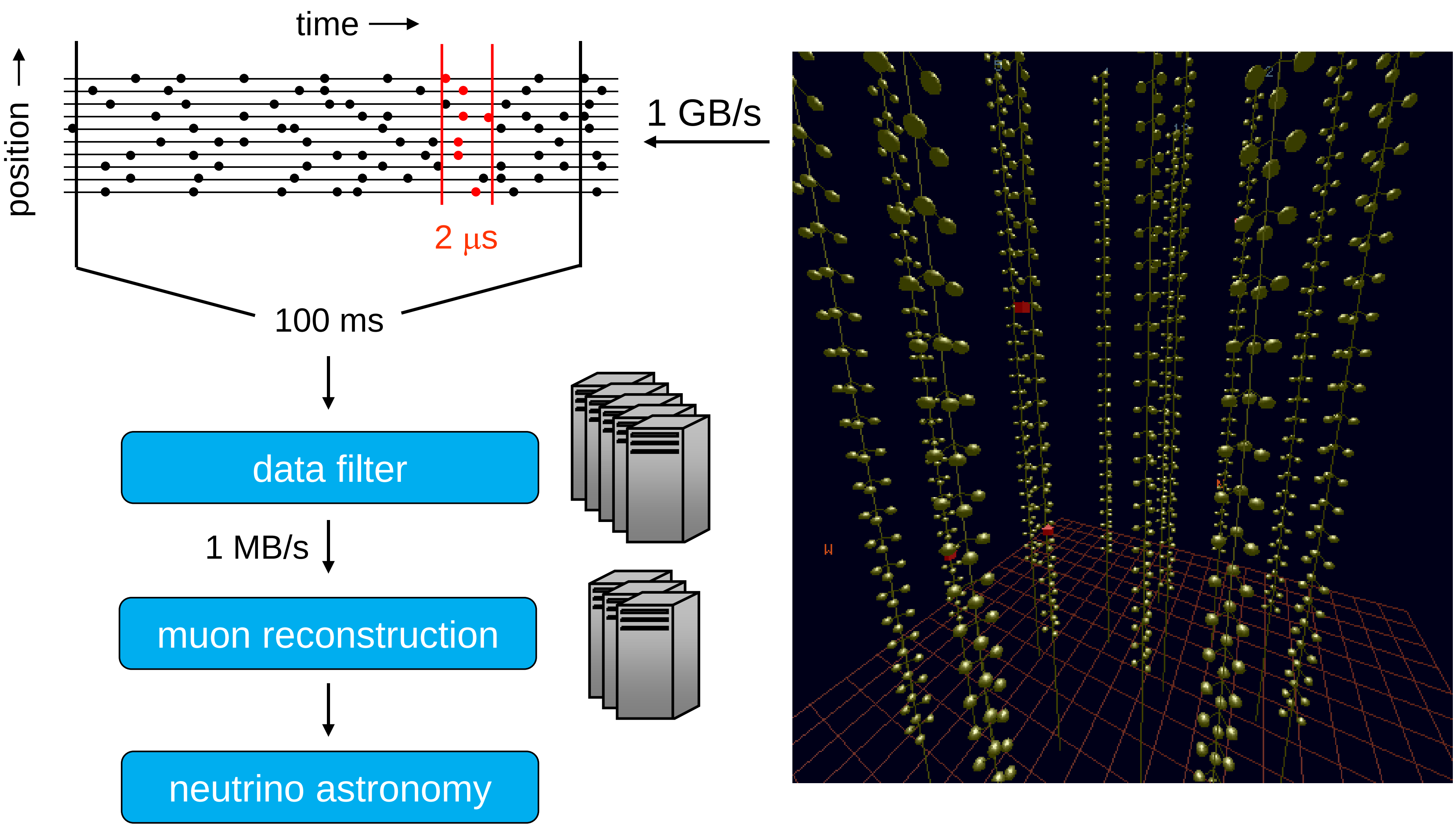
Detection unit



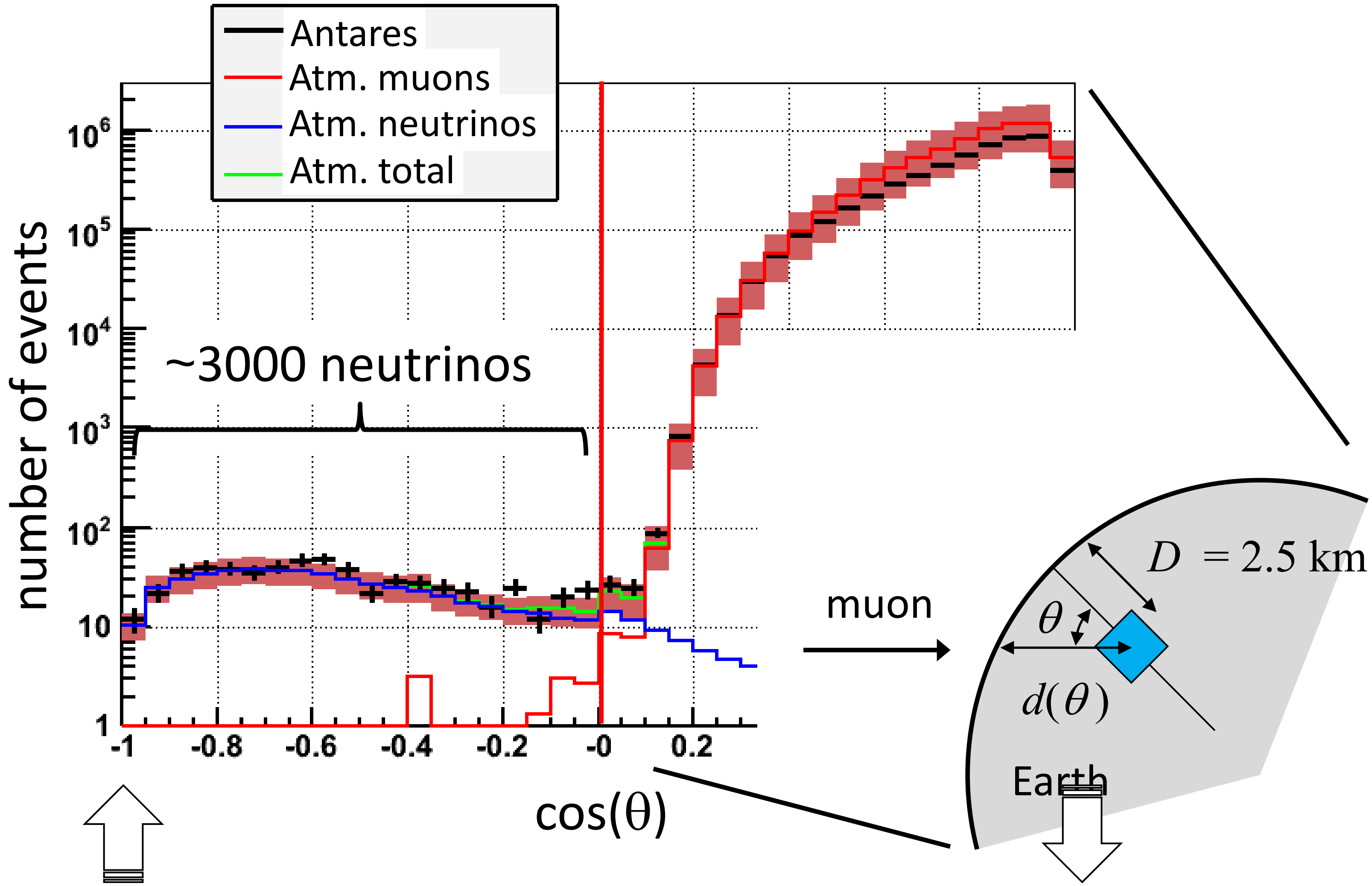


Modularity of detector
requires deep-sea connections!

All-data-to-shore



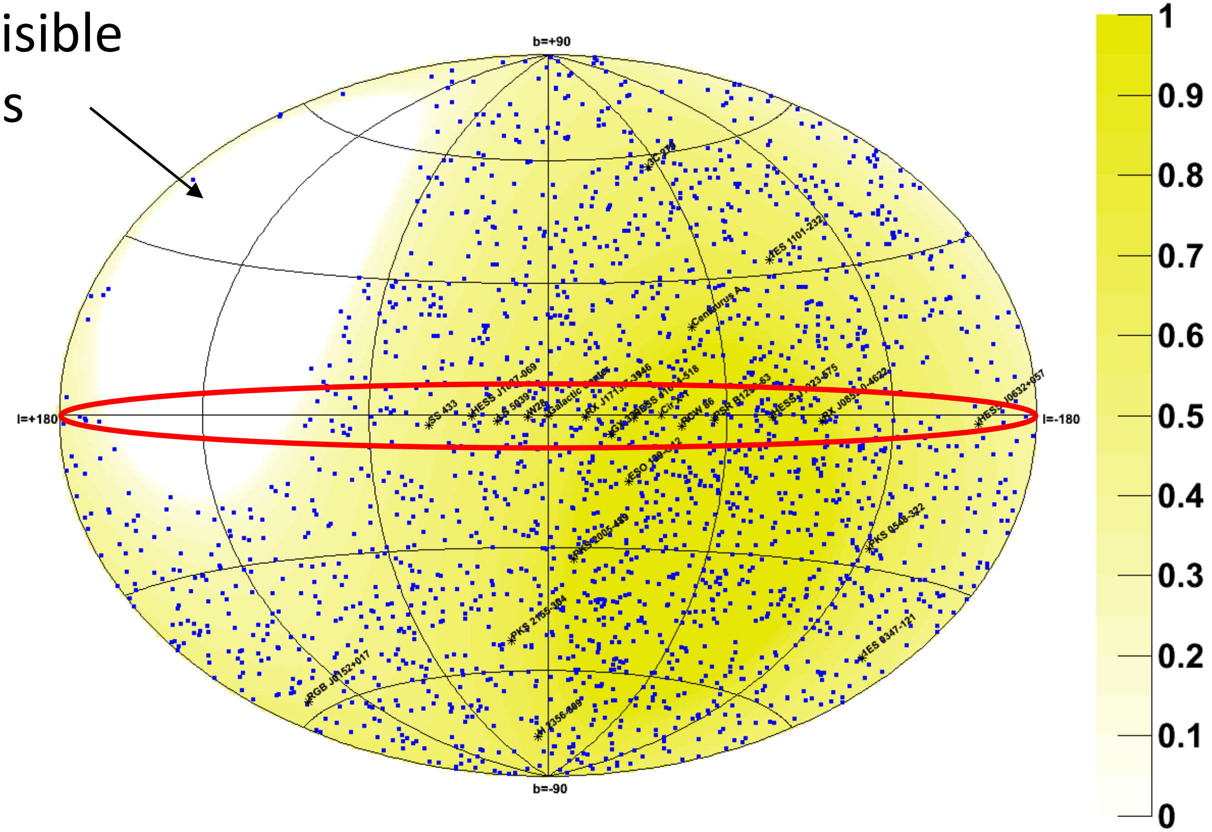
Neutrino detection



Neutrino “sky map”

part of sky invisible to Antares

Galactic plane



No point sources found yet

Future plans

KM3NeT: A KM^3 Neutrino Telescope

Detection unit

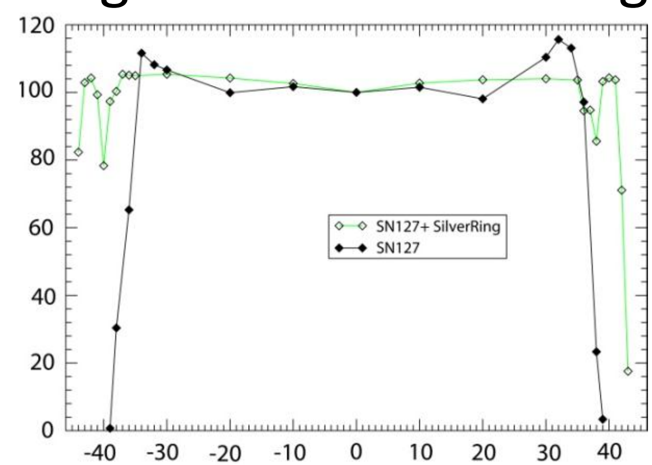
17 inch

31 x 3” PMT

□

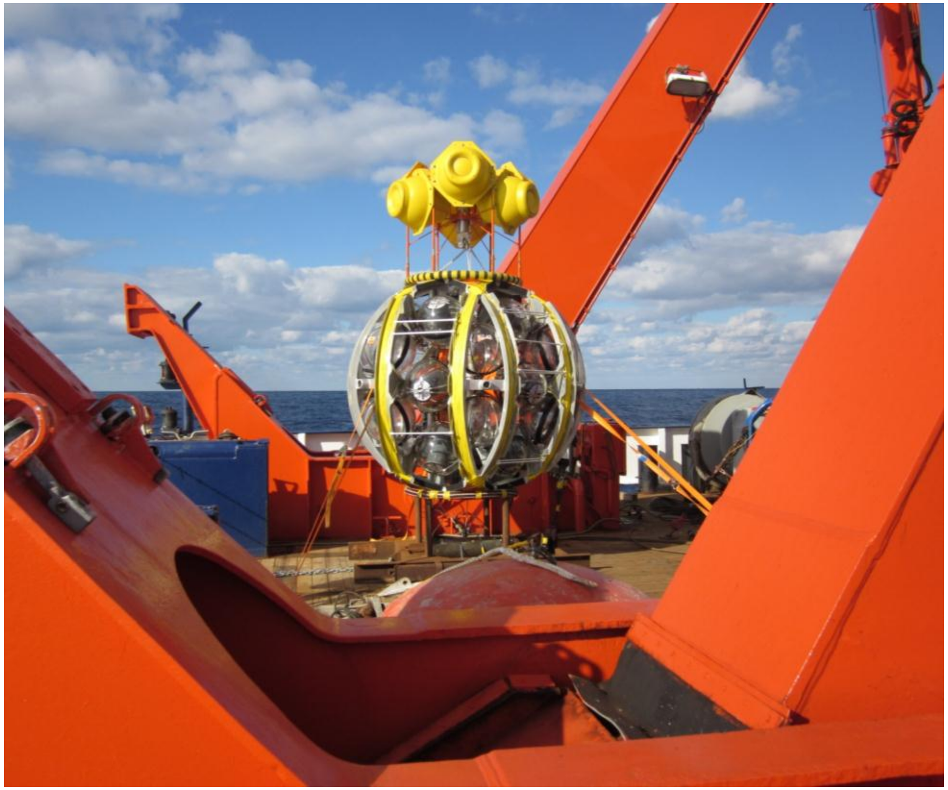
3 x 10” PMT

light concentrator ring



increase of photo-cathode area by 20–40%

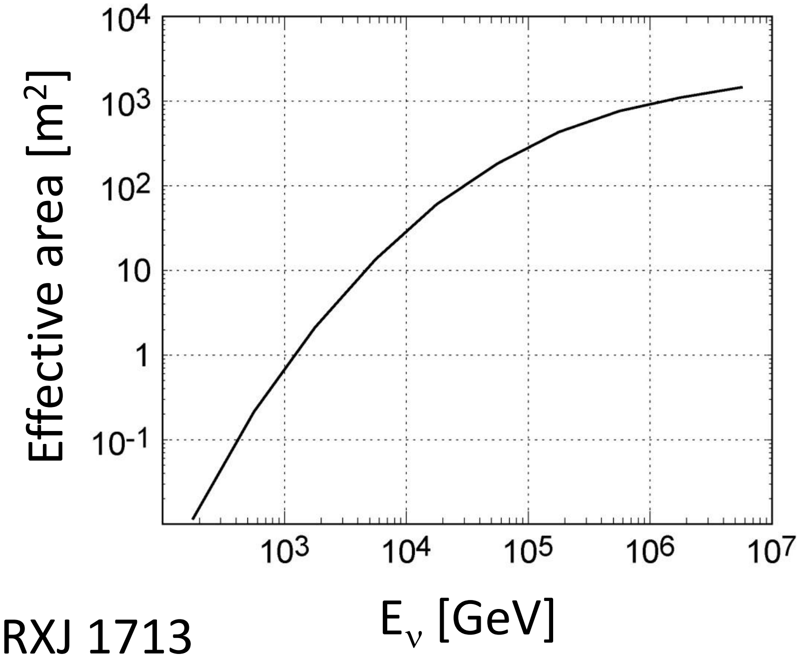
Deployment vehicle



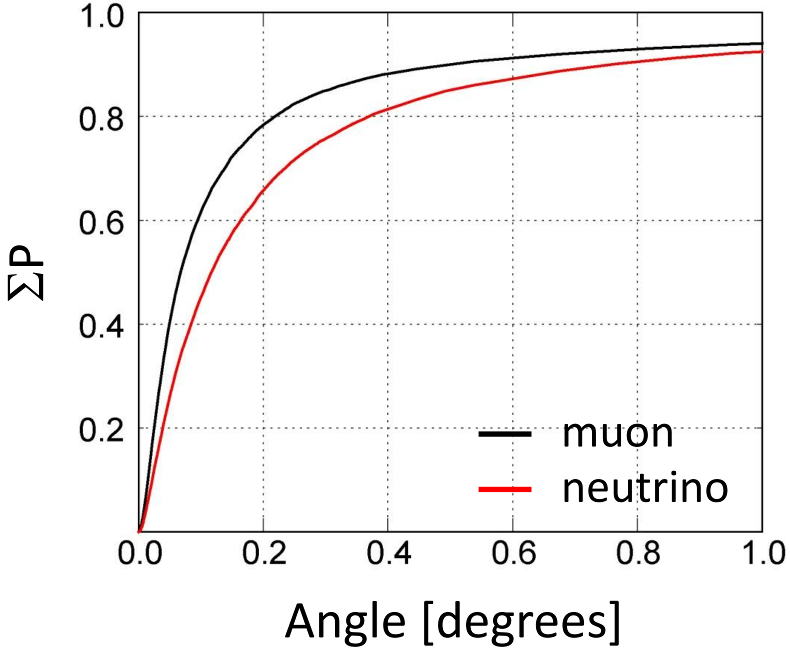
- Developed by NIOZ in the framework of the KM3NeT Design Study
- Fast mounting of strings with sensors (1 person in 2 days)
- Rapid deployment of compact object
- Autonomous unfurling

Performance

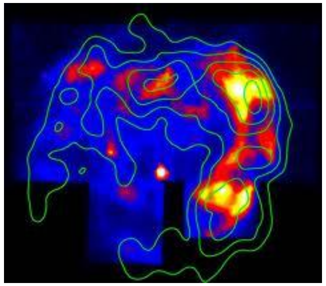
Effective neutrino area



Angular resolution



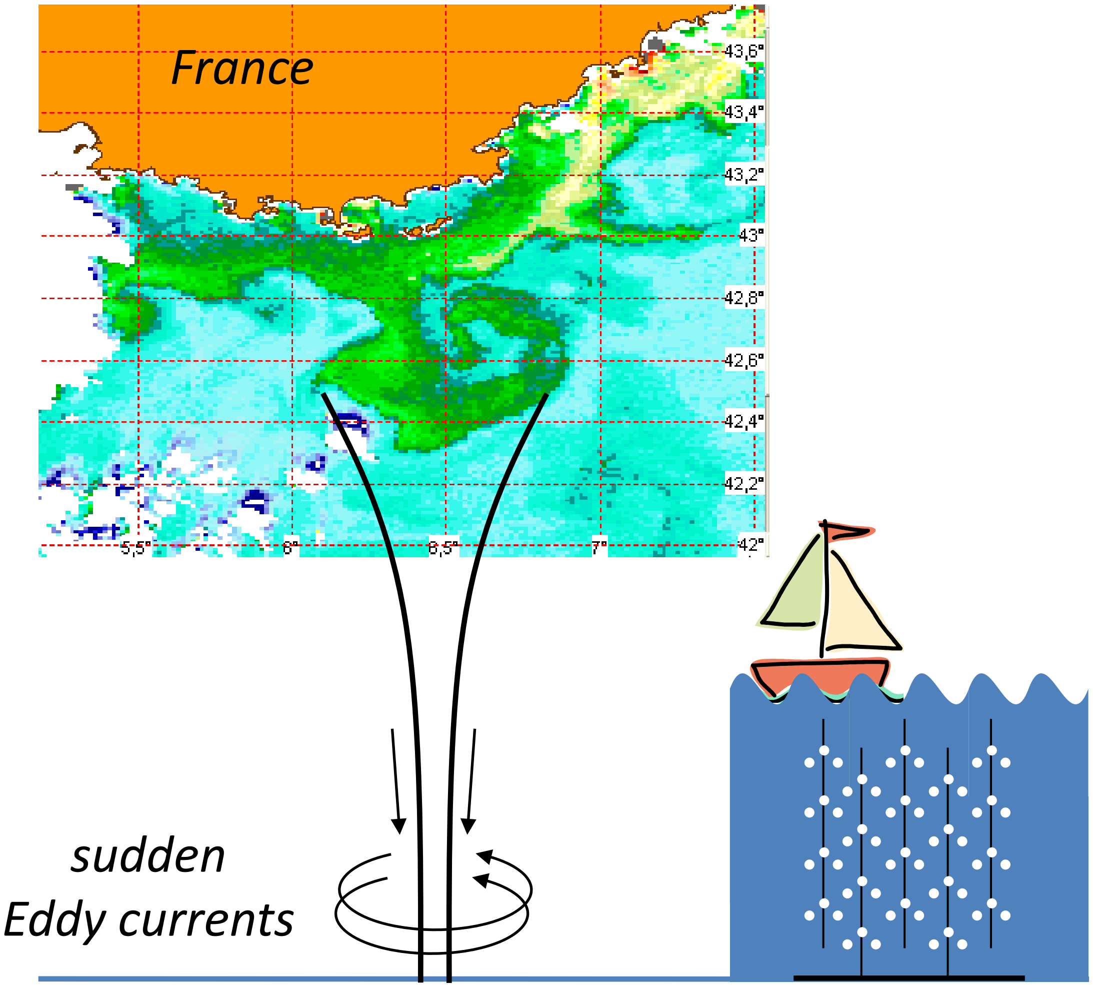
RXJ 1713

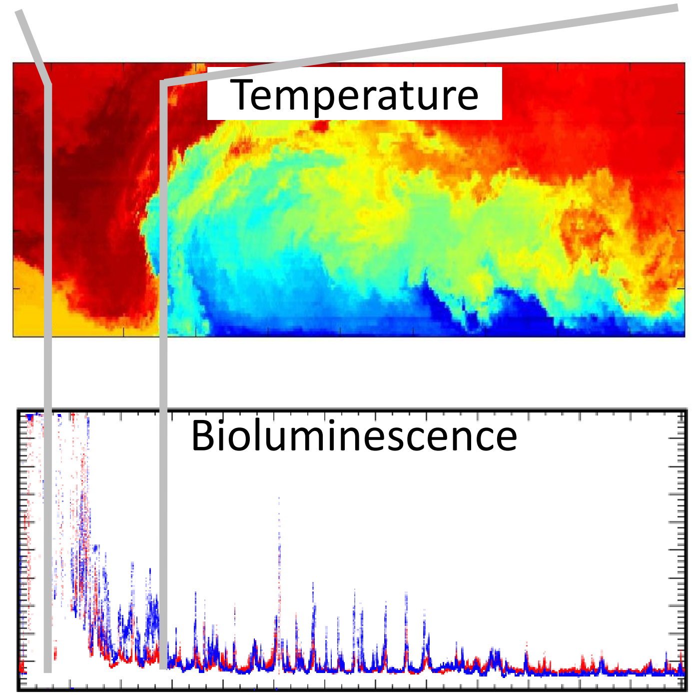


– Supernova remnant "*origin of cosmic rays*"
– 5 sigma discovery in 5 years (5/5)

Earth & Sea sciences

short lived (rare) events
dominate deep-sea life
⇩
permanent observatory





food supply observatory time profile

Summary & outlook

- Low energy neutrinos from the sun and SN1987A have been detected
- Evidence for astrophysical particle acceleration
- High energy neutrinos from other astrophysical sources?

Following the successful construction of the Antares detector as a prototype and the acquisition of start capital for KM3NeT as the future cubic kilometre detector,
today neutrino astronomy is within reach.